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Lord Chancellor Bacon.

Engraved for the Classical Library from an original Portrait in possession of the Author.

Bacon, like Moses, led us forth at last,
The barren wilderness he past,
Did on the very border stand
Of the blest promis'd land,
And from the mountains top of his exalted wit,
Saw it himself, and shew'd us it.
But Life did never to one man allow
Time to discover worlds, and conquer too. *Cowley*

CHEMICAL ESSAYS,

PRINCIPALLY RELATING TO

THE ARTS AND MANUFACTURES

OF

THE BRITISH DOMINIONS.

By SAMUEL PARKES, F.L.S. M.R.I. F.S.A. Ed.

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And of the Wernerian, Horticultural and Highland Societies of Scotland;
Member of the American Philosophical Society, and
Master of Arts of Yale College, Connecticut;
Member of the Imperial Natural History Society of Moscow,
The Academy of Sciences, Arts and Belles Lettres at Dijon,
And the Academy of Medicine at Marseilles;
Honorary Member of the Royal Geological Society of Cornwall,
The Antiquarian Society of Newcastle upon Tyne,
The Agricultural Societies of Philadelphia and Massachusetts, and
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AUTHOR OF
THE CHEMICAL CATECHISM, THE RUDIMENTS OF CHEMISTRY,
&c &c.

THE SECOND EDITION,

Greatly enlarged, and illustrated with twenty-four Plates, of Machinery and Chemical Apparatus.

VOL. I.

London:

PRINTED FOR THE AUTHOR;

AND PUBLISHED BY BALDWIN, CRADOCK, AND JOY,
PATERNOSTER ROW.

1823.

Entered at Stationers' Hall.

PRINTED BY R. TAYLOR, SHOE-LANE, LONDON.

PREFACE

TO

THE FIRST EDITION.

NOTHING can be of more importance to the people of a manufacturing country than the cultivation of a taste for philosophical and chemical inquiries. Manufactories cannot be conducted without the employment of a variety of artificial as well as natural productions, and it behoves the workmen as well as their employers, to become acquainted with the intimate nature and properties of the respective materials on which they have occasion to operate.

To enable such persons to pursue these investigations with advantage, it is requisite that they should not only possess a knowledge of the elements of chemical science, but acquire also a constant habit of observing the effects which different bodies

produce upon each other, and hence learn to understand the causes of the various appearances which take place in the several operations that come under their own daily observation or particular superintendence.

To promote this desirable end, nothing would perhaps be so effectual as the dissemination of several distinct and familiar treatises on the most important manufactures of the country, and on the nature of the materials employed in them. The Essays of Bergman, Scheele, and Watson, are of this nature; and these have contributed in no small degree to the information of the public mind, and to that growing taste for chemical pursuits which is one of the characteristics of the present age.

The subjects on which these eminent Essayists have so ably written, are, however, comparatively few, and much remains to be done before an inquirer into the nature and extent of the British manufactures can obtain solid and sufficient information respecting the staple products of the country.

In the course of his business as a manufacturing chemist, the author of the follow-

ing work has, for many years, been in the habit of visiting the principal manufactories of these kingdoms;—of associating occasionally with the most intelligent artists in a great majority of the counties of England and Scotland;—and of taking notes of every thing that he saw or heard in the course of his journeys which he esteemed worth registering:—he therefore flattered himself that he possessed the means of increasing the stock of general knowledge, and that he might, without presumption, aspire to the honour of treading in the footsteps of those illustrious predecessors above mentioned.

In selecting the subjects, the author has fixed upon those which seem to have been the least examined by other chemical writers, and in all cases due attention has been paid to the improvement of the manufactures of the kingdom. With this view, he has been careful to offer, on every favourable opportunity, such hints as were likely to be most useful to the superintendents of manufactories, and such as should induce a correct chemical investigation of the nature of all those concerns in which persons of this description are usually engaged.

To attain this object, it has been found necessary to recite many chemical axioms, and to impress these upon the minds of artificers and workmen, though such may appear to the proficient in chemical science to be little more than mere truisms or trite observations. In like manner, some of the details are given with no other view than to inform those who are beginning the study of chemistry; and this may be instanced in the enumeration of the many cases in which a knowledge of specific gravity is essential, and where the author's sole aim is to induce such persons to direct their attention to this particular and important subject.

The superintendents of some manufactories may perhaps deem it superfluous to have described their processes so much in detail, because they themselves are already familiar with them; but such individuals should consider that others may profit by the perusal, and that those who are engaged in very different occupations, by reading such accounts may perceive that the improvements which are suggested for the adoption of other establishments can, with considerable efficacy and saving, be applied to their own, and thus in the end

a great mass of improvement may be gained by the community at large.

It is an excellent opinion of the writer who obtained a prize from the Economical Society of Berne, for an Essay on the best means of instructing the public, that "a labourer executes easily and exactly all his works in proportion to his knowledge;—that the ignorance of the people always throws an indolence on the persons of a more elevated order;—and that the intelligence of the artist necessarily excites the emulation of the gentry and the nobility."

Many years having now elapsed since the author began to register every thing of importance that he saw or read respecting the British manufactures, it has become impossible for him in some instances to ascertain whether the facts were obtained from books, or from observation during his intercourse with artists and their employers; and at this distant period he is unable in some cases to discover even whether the language itself is his own, or that of others. He has, however, endeavoured to make his readers amends for this uncertainty, by referring them on every subject

to the best writers within his knowledge; being ambitious that his work should be received as a book of reference to the most eminent chemical authors, so far as these have any thing applicable to the subjects on which he treats. It must always be an acceptable service to those who have chemical subjects to investigate, to be directed to original authorities, or otherwise to faithful translations, which can always be procured by many readers with greater ease than those works which are printed abroad, or even than any of the foreign Journals.

Notwithstanding the space which is occupied by such allusions and authorities, the author hopes that these volumes will be found to contain as large a proportion of *original* matter as any chemical work of the present day; and it is impossible in this advanced state of the science to write on any chemical subject, without recapitulating many facts which have been already established by a host of predecessors in the same walk of science. "Do not blame me," said Macrobius, an interesting Latin writer and eminent critic of the 4th century, "if what I have collected in reading shall frequently be expressed in the very words of

the authors from whom I have taken it; for my view in this work is, not to give proofs of my eloquence, but to collect and digest, into some regularity and order, such things as I thought might be useful to be known to the public*."

In accomplishing a similar task, the author is aware that he is liable to mistakes and misconceptions, especially in his reasonings and remarks on the conduct of those manufactures in which he has never been personally engaged: he is however convinced, as Dr. Priestley has observed, "that a person who means to serve the cause of science effectually, must often hazard his own reputation so far as to risk mistakes in things of small moment†." And if it behoves one in the service of *general* science to risk that which is so valuable to every man, surely those branches of knowledge which are more intimately connected with the commerce of these dominions have the most imperious demands upon us; for "what can touch us more nearly than the improvement of our manufactures, on which

* Præfat. ad *Saturnalia*.

† Preface to Priestley's *Observations on Air*, Edit. 1781, vol. i. page 9.

the riches of our country, and the daily bread of the greatest number of its inhabitants depend*?"

Deeply engaged in a manufactory, which demands great attention and often requires the aid of tedious experimental investigation, little time could be afforded for preparing these volumes, except in those hours which the generality of men devote to relaxation or repose.

The greater part of these Essays were, therefore, necessarily composed during the intervals of business, and often in the midst of manufactories at a great distance from home, when the author could have no access to his own library, or to books of any kind to which he might refer for authority or elucidation respecting the numerous facts which always offer themselves to the attention when treating on chemical or philosophical subjects.

From these circumstances, the Essays were at first written without any illustrations or references whatever, and the notes were appended occasionally, wherever fur-

---

* *Experiments on Bleaching*, by Francis Home, M.D. page 147.

ther explanation seemed to be essential, and whenever the reading or the memory of the author furnished him with any facts of importance to which he had not already alluded. It must however be remarked, that this mode of essay-writing, though it may perhaps give a little more originality to the complexion of the composition, has entailed upon the author the very laborious task, of subsequently collecting and examining numerous authorities, in order to enable him to direct the chemist or artisan to the most authentic sources from which he could derive additional and often very valuable information.

To render these Essays more useful, the author has taken considerable pains to procure drawings of all the modern apparatus to which he has referred. These drawings were in general either sketched by himself, or by those proprietors of the several manufactories who were anxious to contribute to the work, and whose kind assistance he hereby acknowledges with gratitude.

Thus all the plates were engraved from *original* drawings, with the exception of the sal-ammoniac apparatus, which is copied from the second volume of the *Journal de*

Physique. This it appeared desirable to describe, because it has not yet excited that attention which its importance and utility deserve, and few persons in this country have access to the early volumes of the foreign journal from which it was obtained.

Great care has also been taken in describing all these plates; and in order to enable the reader to construct any of the apparatus, accurate admeasurements have been given wherever there appeared to be a probability of their being useful.

The pleasure which arises from the discovery of any facts not generally known; any new elucidation of interesting truths; or the acquisition of any scarce treatise which might afford important hints to the reader; and the prospect of completing a work which is likely to be useful to the public, have been constant incitements to the author to persevere in the labour of research with unremitting zeal and ardour.

As a considerable mass of materials still remains with the author, he may perhaps be inclined, should it meet with the approbation of the public, to compose at some future period an additional volume of these Essays. At all events, he will continue to

employ the latter years of his life in the same kind of investigations, always keeping in view the examination of every new improvement in the management of the national manufactures, well knowing that the acquisition of one new idea often gives birth to others of very superior importance.

Cardinal Farnese one day found Michael Angelo, when an old man, walking alone in the Colosseum, and expressed his surprise at finding him solitary amidst the ruins; to which he replied, "I go yet to school that I may continue to learn." Whether the anecdote be correctly true or not, it is evident that he entertained this feeling, for there is still remaining a design by him, of an old man with a long beard in a child's go-cart and an hour-glass before him, emblematical of the last stage of life; and on a scroll over his head, ANCORA IMPARO in Roman capitals, denoting that no state of bodily decay or approximation to death was incompatible with intellectual improvement. "He established it as a principle," says Mr. Duppa*, who has given us these anecdotes, that to live in credit

* *The Life of Michael Angelo Buonarroti, with his Poetry and Letters*, by R. Duppa, Esq. 4to, London 1806.

was enough, if life was virtuously and honourably employed for the good of others and the benefit of posterity :—and thus he laid up the most profitable treasure for his old age, and calculated upon its best resources ;—making all nature interested in the length of his days."

London,
July 8th, 1815.

PREFACE

TO

THE SECOND EDITION.

A CONSIDERABLE time has elapsed since the publication of the first edition of these Chemical Essays; and during this period so many new facts have been discovered, and the opinions of the most eminent chemists of every country have so entirely changed respecting some of the more interesting branches of Chemistry, that the very elements of the science have in several instances undergone a complete revolution.

On these accounts it became necessary, when preparing a new edition for the press, not only to revise every page of the work with the utmost care, but also to enlarge most of the Essays by the addition of much new matter.

It would be useless to attempt to enume-

rate the whole of the additions and alterations which this impression has undergone; but a few of the most important may be mentioned, for the information of those persons who may not have seen the former edition of this work.

When these Essays were written, the importance of the doctrine of definite proportions was not so generally acknowledged as it is at present; for though Higgins, Richter and Dalton had all written on the subject, it seems never to have made a general impression on the public mind, until Dr. Wollaston in the year 1814 published his Memoir on Chemical Equivalents, and with it the sliding-rule, which reduced the theory to practice, and convinced all scientific men of the importance of these helps in chemical inquiries. It was therefore thought to be of consequence, in republishing these Essays, to attach the representative number to every substance treated of therein; and this has been done in most cases.

The Notes which in the former edition were printed at the bottom of the page have been for the most part interwoven with the Text; and in order to make each

Essay a complete Treatise on the subject which it professes to discuss, the various salts and other chemical compounds connected with it have been enumerated, and their properties and uses, where known, fully described. The Essay on the Manufacture of Tin-Plate, first printed in the Memoirs of the Literary and Philosophical Society of Manchester, is now appended to the former Essays;—a List of the various works referred to in these volumes is also given, for the purpose of showing the editions which have been made use of, and for enabling the reader to examine the extracts and verify the quotations;—and much labour has been bestowed in forming a New General Index.

The most important addition, however, is that of a very extensive Table of Chemical Equivalents. This Table has been drawn up in an alphabetical form for the sake of facility of reference; and it may be remarked that it is the only alphabetical Table yet published by any English Chemist which contains the chemical composition of each compound attached to its equivalent number. In choosing these numbers, I have adopted those which appeared to me to be

derived from the best authorities, though I am well aware that a long time must elapse before any Table of this sort can be formed which will be correct in every instance.

The writers who have treated more expressly on this subject are Berzelius and Dr. Thomson; but the largest collection of modern equivalent numbers has been published by Mr. Brande in his Manual of Chemistry, and of this I have availed myself very much in the construction of this Table. Another Table has since been published by Mr. Brande, which in many respects varies very considerably from the numbers in his Manual; but as many of these appeared to me to require confirmation, I thought it most advisable to construct my Table in conformity with the numbers which I had already made use of in the body of the work.

I have much pleasure in adding, that these Essays have been twice translated into the French language, and are now selling at Paris in three volumes octavo; and that they have also been rendered into German at Weimar, at Erfurt, and elsewhere.

Mecklenburgh Square,
June 1823.

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DESCRIPTION OF THE PLATES

IN

THE FIRST VOLUME.

PLATE I.

PORTRAIT OF LORD BACON.

THIS is a highly-finished likeness of Lord Chancellor Bacon, engraved by an eminent artist from an original portrait in the possession of the author. The lines underneath it were taken from a poem addressed by Abraham Cowley to the Royal Society, on its first formation, and printed in Bishop Sprat's History of the Society.

PLATE II.

A SECTION OF THE BLACK LEAD MINE AT BORROWDALE IN THE COUNTY OF CUMBERLAND.

In looking at this plate it should be recollected that the mountain is 2000 feet high, and that the present entrance into the mine, marked B E, is at an elevation of about 1000 feet above Borrowdale, and consequently that this is a section only of the *upper* part of the mountain.

A is the house which was built for the security of the mine, as mentioned at page 442 of this volume, the ascent to which from the vale is by a narrow, tedious and circuitous path.

B represents a rail-way which has been made from the surface of the mountain into its interior for the purpose of wheeling out the black lead, and likewise the earth which the workmen find it necessary to remove before they can obtain it.

C is the passage from the inner part of the house, by which the workmen are allowed to enter the mine, as particularly mentioned at page 442 of this volume.

D is a water blast shaft for giving air to the mine.

E represents the main rail-way mentioned already under letter B. Its length is 660 feet.

F shows the direction of the old entrance into this valuable mine.

G the old level by which the mine was formerly worked.

H H represent the large leader, measuring in length 318 feet.

I marks the spot where a rich mass of black lead was discovered on the 6th of May 1812.

K K are what are called *trial leaders*, cut for the purpose of further discovery. Near the upper one of these letters the men were at work when I visited the mine in the year 1814.

L is intended to point out a large vein of black lead discovered in the year 1803.

M is merely a leader to the above vein.

N is meant to point out the direction of several trial leaders cut at different times for the purpose of discovery.

O. Here lay a very rich mass of black lead which was discovered in the year 1778.

PLATE IV.

This plate is the representation of a new APPARATUS for the distillation of rum in the West Indies, contrived for the purpose of economizing fuel.

A is a still of the usual form.

B is a vessel called the preparatory vessel. The design of this is to prepare the wash by giving it a high degree of temperature, from the waste heat of the still, during the time the still is at work. At the commencement of the operation this vessel and the still are both filled with the cold fermented wash, and the still has a fire placed under it. By inspecting the drawing, it will be perceived that this apparatus is so constructed that the fire, after performing its office underneath and round the sides of the still, passes under the preparing vessel B in a reverberating manner, instead of going off in a direct way, as is usual, to the chimney. This is effected by means of a slight partition wall, brought up underneath the preparing vessel, (as will appear by reference to the ground plan,) and which occasions the flame to take a circuitous turn under that vessel before it passes to the chimney, as already mentioned; the flues being provided with dampers to direct the flame and the heated air either way as the case may require. During the time the still is at work, the wash within the preparing vessel will by this contrivance be brought to nearly a boiling heat.

The design of this construction is, that when the still is worked off, and has been emptied of the aqueous phlegm, the

operator can open the cock of the connecting tube, fixed between the still and the preparing vessel, and thus, with little trouble, recharge the still with fresh wash, which will be of such a temperature that the distillation will recommence almost immediately. In this way the still is charged time after time without the head being removed; and if the preparing vessel be regularly refilled with cold wash, this will become heated in like manner for the next or any future operation. The separate parts of the apparatus may be thus described:

a is the flue under the preparing vessel.

b the man-hole, which is steam-tight and securely fastened down.

c a safety valve.

d the cock which opens or cuts off the communication between the still and the preparing vessel.

g the passage to the chimney.

h the entrance to the fire-place.

PLATE V.

Is an *improved* Still, with its preparatory vessel as lately introduced in some of the West India Islands for the distillation of rum.

On an inspection of the ground plan of this apparatus, it will be perceived that the still, A, is of a square form: but as the bottom and the crown of this still are both curved in the same manner as a round one, the principle on which this acts is nearly the same as that described in Plate IV. except in the following particulars:

The flues under this still reverberate in the direction of the arrows, as shown in the ground plan, and are then taken up on each side of the still into the side flues, from whence the fire or flame proceeds under the preparing vessel B, round a slight partition of brick-work called a *bonnet*, then into an aperture at the bottom of the perpendicular flue, or tube, C, which passes through the centre of the liquor in the preparatory vessel, and from thence directly into the chimney D.

In common stills the heat from the fuel is not sufficiently expended under the bottom, as explained at p. 294, but quickly passes off to the sides, whereby the sides of the vessel are very soon burnt through. By this contrivance, however, the light materials which are burnt for fuel in the West Indies are nearly all consumed under the bottom of the still; and whatever waste heat there may be, this is afterwards expended in raising the temperature of the wash contained in vessel B.

In this apparatus, like the former, b is the man-hole for clearing out the preparatory vessel, c the safety valve, and d the cock for opening or shutting the tube by which the still is filled with heated wash from the preparatory vessel B. The principal difference in the two stills, viz. the one in Plate IV. and the one now under description in Plate V., is in the manner in which the liquor of the preparatory vessel of each is heated. That in the former is heated by the flame passing underneath it, and the latter by a heated tube which is fixed within the centre of the liquor itself, as is more particularly described at page 174.

PLATE VI.

CONTAINING MISCELLANEOUS ARTICLES.

Fig. 1 is a delineation of a glass instrument invented by Dr. Wollaston for producing ice in a peculiar way artificially. He calls it a *cryophorus*. For a further account of this little implement see page 126 of this volume.

Figs. 2 and 3 represent an iron hopper for a furnace with its iron stopper, both of which are described at page 158, &c.

Figs. 4 and 5 are furnace bars, and these are fully described at page 162.

Fig. 6 represents a method of building the end of the fire-place of a reverberatory furnace so that the bars may easily be drawn out for the purpose of clearing away the scoria of the coals, ashes, &c. For some account of the conveniences attending this peculiar construction see page 163.

Fig. 7 is the representation of a bar of iron to be laid within the brick-work of a furnace, to prevent the masonry giving way in consequence of the force of the fire. For some further account of its uses see page 167.

PLATE VII.

The elevation of an *Economical* STILL for general purposes.

A is a still in the usual form. B the copper head with a long pipe passing through the condensing vessel C, to the worm E, fixed within the cask or worm-tub D.

The condensing vessel C, which lies in a horizontal position, and may be supported from the ceiling or the floor, as may be most convenient, answers two important ends in distillation which deserve attention. This preparatory vessel being filled with wash, or any other liquor intended to be distilled, materially cools the gas arising from the still, and condenses the vapour into a liquid, as it passes along the pipe e, before it reaches

the worm itself; and this intermediate reduction of temperature is so considerable, that one-fourth of the water usually employed in the worm-tub is found sufficient. The second advantage arising from this peculiar construction is, that so much caloric passes off from the tube e, into the wash contained in the intermediate vessel c, that the liquor soon becomes heated to 170° or 180° of Fahrenheit; and hence is in a very desirable state for replenishing the still. This is done merely by turning the cock d, in the pipe, which passes from the preparatory vessel to the still. Each end of the pipe passing through the intermediate vessel is secured with cement, that the vessel may at any time be taken off if required.

The orifices b and c, and the cock d, have the same uses as those in Plates IV. and V. marked with similar letters. F is the vessel placed on the ground for the reception of the product of the still. This apparatus is referred to at page 174 of this volume.

PLATE VIII.

A collection of apparatus for ascertaining the specific gravity of bodies.

Fig. 1 is an areometer for proving the specific gravity of fluids; it is described at page 209 of this volume.

Fig. 2. An hydrostatic balance. Its use and the different modes of employing it are explained at page 217.

Fig. 3. A jar of water in which the solids, whose specific gravities are to be ascertained, are immersed, after having been weighed in air.

Fig. 4. A cube of glass. Its use is particularly described at page 209.

Fig. 5 is the representation of a set of carat weights, such as are described at page 226, and which are extremely useful in ascertaining the specific gravity of many substances.—Tables to facilitate the use of these weights will be found at pages 229 and 233 of this volume.

Fig. 6. Knight's travelling case, containing a specific gravity bottle, counterpoise weight, &c.

Fig. 7 is a drawing of Mr. Knight's gravity bottle with taper neck, for ascertaining the specific gravity of fluids where great accuracy is required.

Fig. 8. is the representation of a stopper for a specific gravity bottle, with a notch on one side to allow of the escape of the redundant fluid, as described at page 215 of the Third Essay.

Fig. 9. Mr. Nicholson's specific gravity bottle, with the conical notched stopper (fig. 8.) placed in it.

Fig. 10. The specific gravity bottle, usually employed by the author whenever he has occasion to take the specific gravity of fluids, as noted by the carat weights. The bottle itself is marked on the neck with a diamond to show how high it should be filled, and it is blown with a sort of cup at the top to receive any portion of the liquor which would otherwise be spilled in filling; but this is not well displayed in the engraving. See page 227.

PLATE IX.

Mr. Parkinson's machine for printing three distinct colours at once on calico, referred to at page 307 of this volume.

A. A screw to give the proper pressure to the main roller. There is a similar one at the other end of the machine.

B. A screw to give the necessary pressure to the copper roller C.

C. A copper roller, with one of the patterns engraved on it. This receives the colour from a small box at the top, which could not be shown in the engraving.

D is the main roller of iron, round which the calico passes in order to receive the printed impression from the three smaller rollers C, G and G.

E. A wooden roller to guide the blanket, against which the white calico lies. This blanket could not be distinctly shown in the engraving.

F F. Two blankets to receive the colour from the two colour-boxes H H. On these blankets the respective colours become by the rotary motion uniformly spread by the time they arrive at the rollers G G, on which these are to be deposited.

G G. Two wooden rollers with patterns cut upon them. Each of these, as before mentioned, receives the colour from the blanket F, which moves underneath, and immediately imparts it, in the desired pattern, to the white calico which revolves by an equable motion round the large iron roller D.

H H. Two wooden troughs containing the prepared colour. These the workmen call *colour-boxes*.

I I. Two large wooden rollers, designed to guide and stretch the colour-blankets.

K K. Two wooden rollers revolving within the colour-boxes H H. These are contrived for feeding the blankets with colour.

L. Eight rollers of wood, four of which belong to each colour-blanket. These rollers are merely designed for stretching and guiding the blankets.

M. The large roll of white calico in a prepared state fit for printing.

N. The calico in a printed state, after it has received the

impression of the three patterns, in three distinct colours, from the rollers C, G and G.

Twenty pieces of white calico, containing twenty-eight yards each, and skewered together by their ends, are generally printed by this machine at one operation, it being so contrived that they pass over the three different rollers in one continued uninterrupted line, until the whole is printed. This machine is capable of printing about seven yards of calico every minute.

PLATE X.

APPARATUS IN CALICO-PRINTING.

Fig. 10 is the representation of a steam apparatus for drying calicoes. A A A A A A are six distinct hollow copper rollers containing steam. Round these the damp calico is wound in succession, by a power acquired from a steam engine, and by the heat of these cylinders the cloth is completely dried. B B B are three fans or vanes, also moved by the steam engine, and calculated for promoting a perpetual circulation of air to expedite the drying process. C is the heap of damp calico intended to be dried. D the calico as it is wound off the cylinders in a dried state.

Fig. 11 is an apparatus for printing pencil-blue on calicoes, with greater certainty than has ever before been attained. It is fully described at page 290.

PLATE XI.

A barytes-furnace, contrived for the decomposition of Derbyshire cauk, or the common sulphate of barytes.

Fig. 1. is an elevation of the furnace, as it appears when finished. Fig. 2 is as it appears before the arches are turned over it.

A is the ash pit. B the fire-place, with the fire-bars. C the bottom of the furnace on which the ground cauk mixed with the carbonaceous matter is to be exposed to the action of the fire, with continual stirring. D is the chimney for carrying off the smoke, the sulphurous acid gas, and other incondensable products. E a door for emptying the ash-pit. F the furnace arch and opening to repair the furnace. G the hopper for feeding the fire. H H the doors into the furnace for the convenience of stirring the materials, and through which the sulphuret of barytes is to be withdrawn when finished. I the arch of the fire-place.—For the method of using this furnace see page 361.

PLATE XIII.

APPARATUS FOR MAKING COKE.

Fig. 1 represents the ground plan of one of the coke-ovens belonging to His Grace the Duke of Norfolk, at Sheffield in Yorkshire, communicated by Mr. Curr, steward to His Grace.

The oven is built circular, with a wall of two bricks length, or 18 inches, in thickness. Its diameter is ten feet in the clear within side, as will be seen by a reference to the scale.

A is the platform or floor of the oven, which is elevated three feet above the ground, as will appear from an examination of the elevation fig. 2. This is contrived for the convenience of placing a wheelbarrow under the door to receive the cokes as they are drawn from the oven.

B is the opening or door-way for drawing out the cokes. It is 2 feet wide and 19 inches high to the springing of the arch. This door-way has a broad cast-iron sill built into the wall when the furnace was erected.

C. The oven wall, which is 18 inches thick and 19 inches high, when measured from the floor of the oven. The diameter is then contracted, and the roof is brought in like a glass-house, to the height, when measured perpendicularly, of 3 feet 5 inches more, leaving a circular opening of two feet diameter at the top, for supplying the furnace with the coals which are to be converted into coke, and to serve as a chimney when the coals are first ignited. The latter wall is only one brick's length in thickness, and the *ends* of the bricks are placed towards the fire. The floor is laid with hard common bricks on the edge; common bricks are also sufficient for the first wall of 19 inches high, but it is absolutely necessary to have good fire brick for the whole of the arch or covering.

D D is a wall built with common unhewn stone, about 20 inches thick, and carried up the whole height of the oven, the void spaces in the corners to be filled with soil or rubbish and well rammed. It may be observed that it would be economical to build a furnace of this kind on the side of a hill, with the space it occupies cut out of the bank. Care must, however, be taken to build it in such a way that no air shall enter through any of the brick-work into the body of the furnace.

Fig. 2 represents a front elevation of the coke oven, the ground plan of which has been described already.

In explaining this elevation, reference must be had to the letters engraven upon the plate.

C is intended to show the line of the oven floor.

D. The height of the oven wall where the brick-work begins to contract.

E. The door-way for taking out the cokes when sufficiently burnt.

G G shows a section of the arched roof of the oven; but this is not seen in the front elevation, as the front wall and the backing of earth hide it.

The coke ovens are used thus:—Small coal is thrown in at the opening fig. 2, sufficient to cover the bottom of the oven 19 inches thick to the springing of the arch, which is about two tons; they are then levelled, and the door E built up with loose bricks. The heat of the oven sets the coal on fire, which is accelerated by the atmospheric air rushing in through the joints of the loose bricks in the door-way. In the space of two or three hours the door-way is plastered up with a mixture of wet soil and sand, except the top row of bricks, which is left unplastered all night. This is generally plastered up close in about 24 hours after the coals are first put in, the chimney remaining open till the flame is gone, which is generally quite off in 12 hours more. A few loose stones are then laid over the chimney, and those covered up with sand or earth. After this is done, the cokes remain in the ovens 12 hours longer, and are then drawn out into wheelbarrows and carted away by the customers. The whole takes up 48 hours; and as soon as the cokes are raked out, the ovens are re-filled with small-coal for another burning.

Fig. 3 represents a new mode of burning cokes in the open air by means of a large chimney round which the coals are piled. The method of managing this process is fully described at page 431.

PLATE XIV.

A representation of the yard of a sulphuric acid manufactory walled entirely round, with all its requisite buildings and offices.

A A A A represent four chambers of combustion, made with sheet lead, each 50 feet long and 20 feet wide.

B is the main reservoir of lead, sunk within the ground for containing the weak acid from the chambers. It is 12 feet by 8 feet, and may be of any convenient depth.

C is a wooden trough, lined with lead, to convey the acid from the chambers of combustion to the reservoir. This trough should be always in its place; and when the operator wishes to empty the floor of any one of the chambers, he runs it off, by means of a syphon of glass or lead, into the trough, which conveys it without any loss into the reservoir.

D. A leaden pump fixed within the main reservoir, for supplying the five leaden boilers E with acid, as the contents of

the said boilers become concentrated by evaporation of the water.

E E E E E. Five leaden pans, or boilers, five feet by seven feet each, for concentrating the acid by steaming.

F is designed to mark nine pillars either of wood or bricks, for supporting the beam of a shed-roof, it being always advisable to erect such apparatus under a shed, which is thus open on one side for the free access of atmospheric air, and the egress of the aqueous and sulphurous vapours which constantly arise from the boilers.

G. A reservoir, four feet by six feet, for containing the concentrated acid when it is run off from the steam boilers. This should have a close cover, to prevent the acid from becoming weak by absorbing water from the atmosphere.

H is a ground plan of the retorting-room, where the concentration is completed by boiling the acid, which has already been steamed in the vessels E in retorts of glass. This room is 50 feet by 20 feet.

I marks the situation of an open shed supported by pillars like the shed F already described. This place is intended for packing the large glass bottles, or carboys as they are called, when filled with the sulphuric acid. It is 20 feet by 56 feet.

K. A warehouse for storing the bottles of oil-of-vitriol, after it is packed ready for sale. The size of this room is 20 feet by 70 feet.

L. The counting-house.

M. Store-room for salt-petre.

N. A store-room for brimstone.

O. The pounding-room, or place where the sulphur is ground and mixed with the nitre ready for combustion.

P is designed for a stable and cart-house.

Q is a small private room for keeping tests, instruments for taking specific gravities, and other things necessary for the use of the proprietors themselves.

R. The main entrance into the yard, with a covered lobby for the convenience of persons in waiting, and to prevent the introduction of improper people into the manufactory.

S is a circular building for coals. This is placed in the centre for the convenience of supplying all parts of the manufactory.

T. A pump for supplying the lead-houses with water.

U. Another pump for giving water to the yard in general, for washing bottles also, &c.

W is a large building for storing empty bottles, baskets, or other things belonging to the manufactory.

PLATE XV.

This engraving is the representation of an elaboratory constructed for the express purpose of preparing the crystallized citric acid.

A A A are pipes of lemon-juice, supposed to be in the state in which the article is usually imported.

B is a large wooden vat for saturating the acid with calcareous earth, and capable of holding two or three hundred gallons.

C C. These are copper pumps suitable for pumping the juice from the casks into the saturating vat.

D is a large wooden tub for decomposing the citrate of lime by means of sulphuric acid, when it is removed from the vat B.

E is a leaden boiler of an oblong square for concentrating the acid liquor from the vessel D.

F F are two round boilers of lead of different sizes, and suspended in water baths. These are employed for the further concentration of the liquid citric acid. In the smaller of these the acid is brought to that syrupy state which is most suitable for it to be laid out to crystallize.

G G G G. These are pans of earthenware or glass into which the concentrated acid is poured to cool and crystallize.

H is a leaden syphon to be employed in running off the waste liquor from the vat B when the acid has been abstracted from it by the chalk.

K is a shelf for holding bottles of chemical tests, trial glasses, or any other small articles required in the manufactory.

L a moveable strainer for clearing the mother liquors, and other purposes of the manufactory.

Plate II.
J.C. David sculp.

Pl. III.

An Apparatus for Boiling Sugar by means of the Circulation of Heated Oil.

Fig. 1. The Elevation.

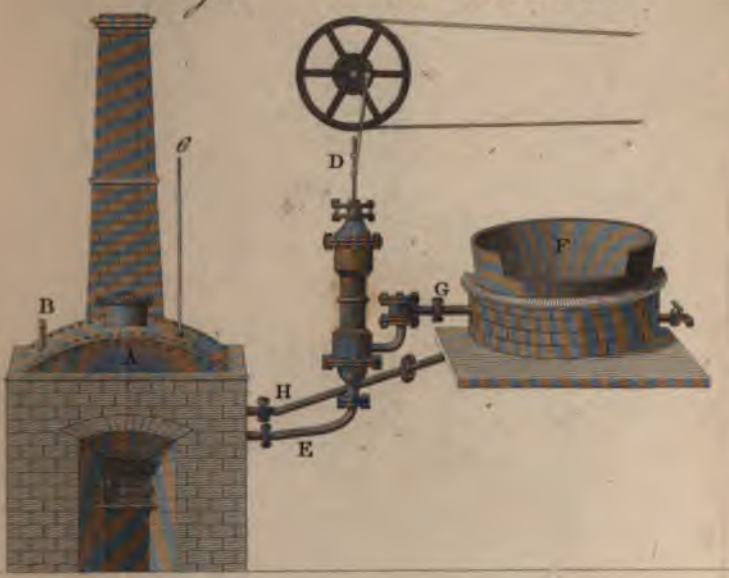
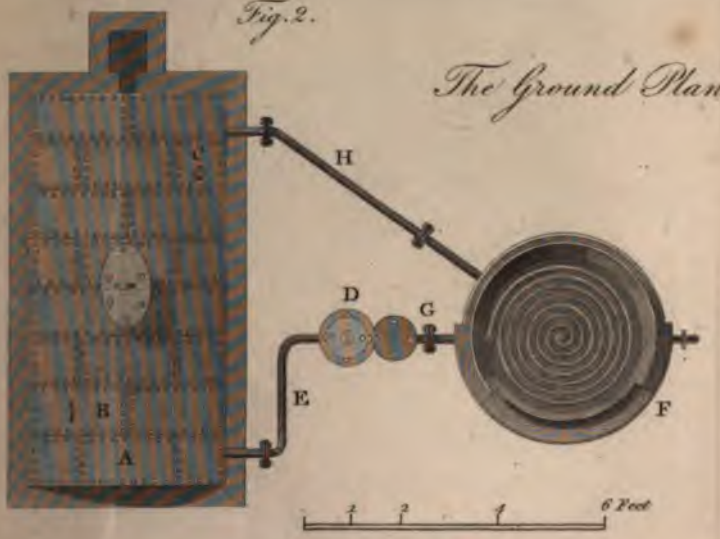


Fig. 2.

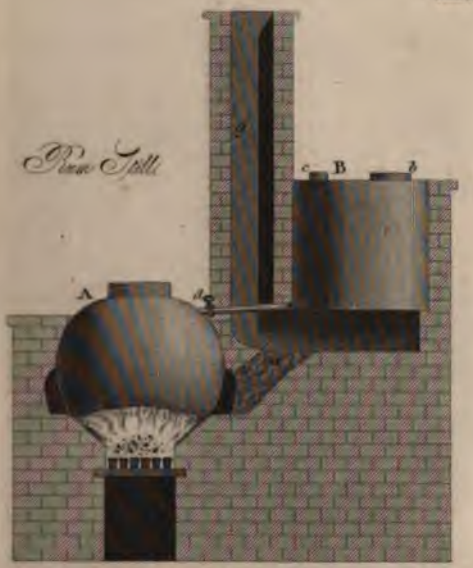
The Ground Plan.



R. Cairns sc.

Plate IV.

Pneu. Still

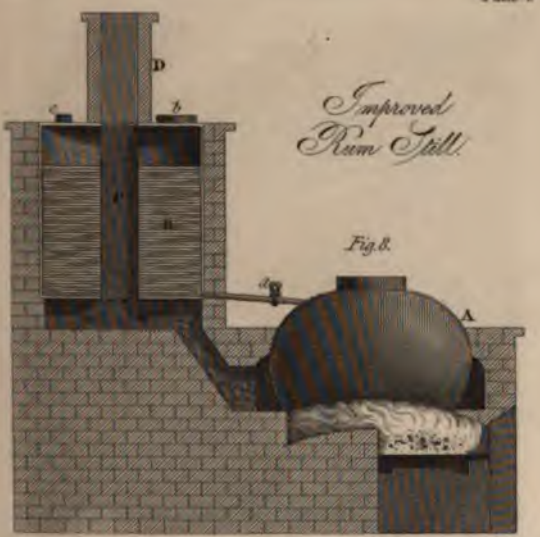


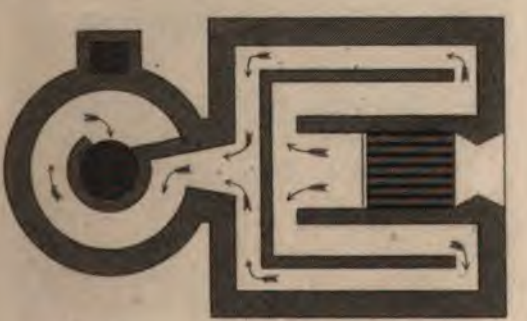
A. The Still..... B. Preparatory Vessel.
a. The Fire..... d. The stop cock.....
b. The Manhole..... g. Passage to Chimney.
c. Safety Valve..... h. Entrance to fireplace.

Plate V

Improved Rum Still.

Fig. 8.





A. The Still..... B. Preparing Heat.....
C. Perpendicular Flue..... D. The Chimney.....
b. The Man hole..... c. The Safety valve.....
d. The Stop cock to cut off the communication.

An Apparatus for Boiling Sugar by means of the Circulation of Heated Oil.

Fig. 1. The Elevation.

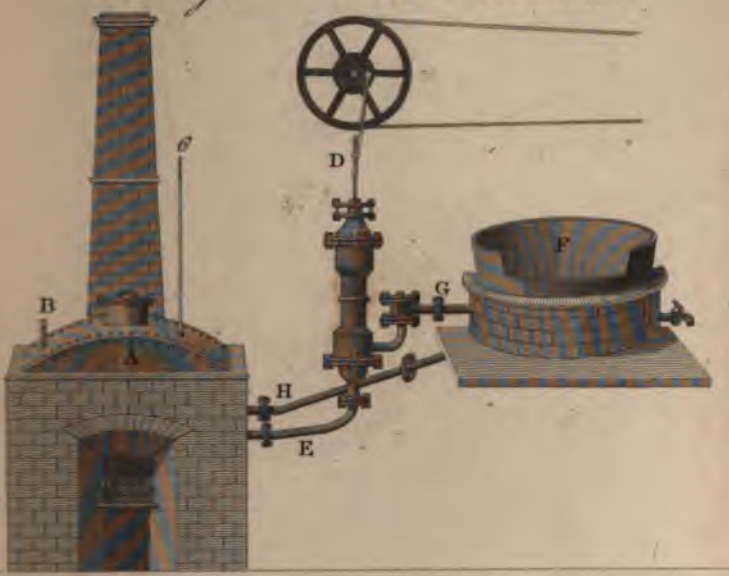


Fig. 2. The Ground Plan.

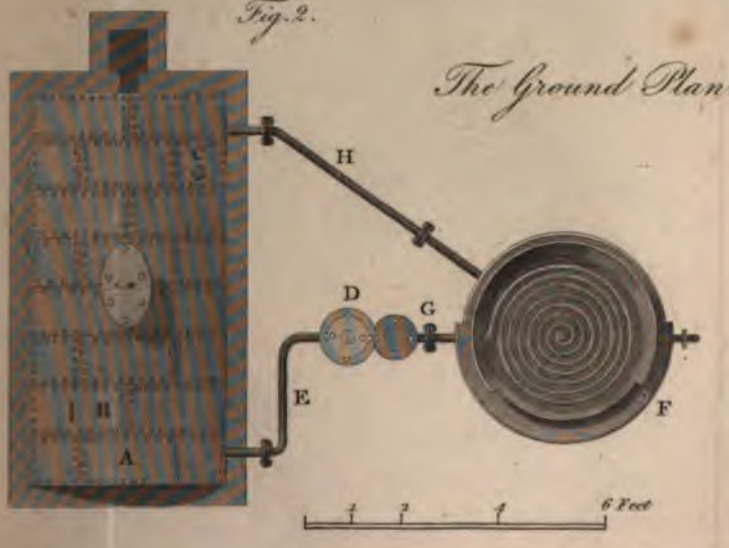
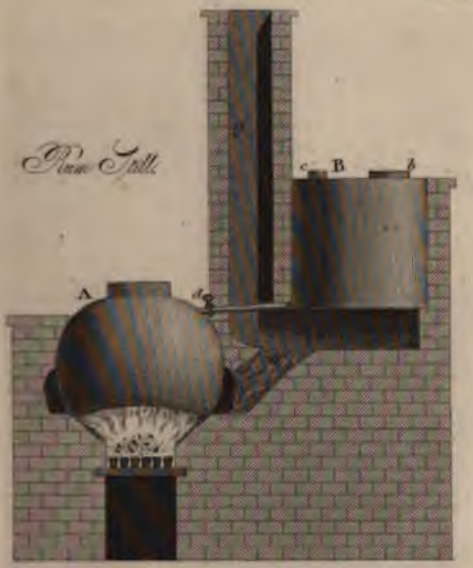


Plate IV.

Plain Still.

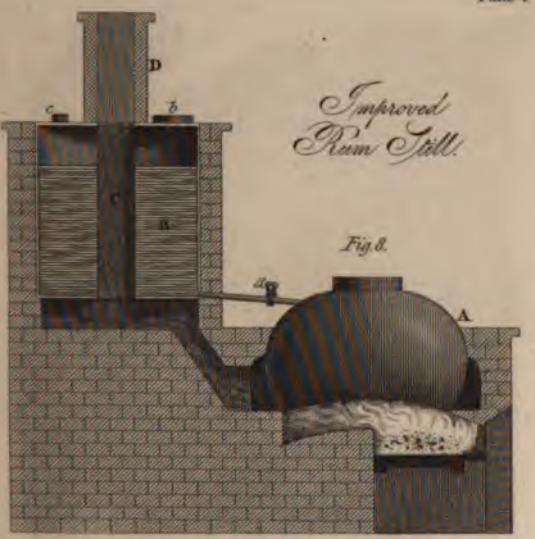


A. The Still.
B. Preparatory Vessel.
a. The Fire.
d. The stop cock.
b. The Manhole.
g. Passage to Chimney
c. Safety Valve.
h. Entrance to fireplace.

Plate V

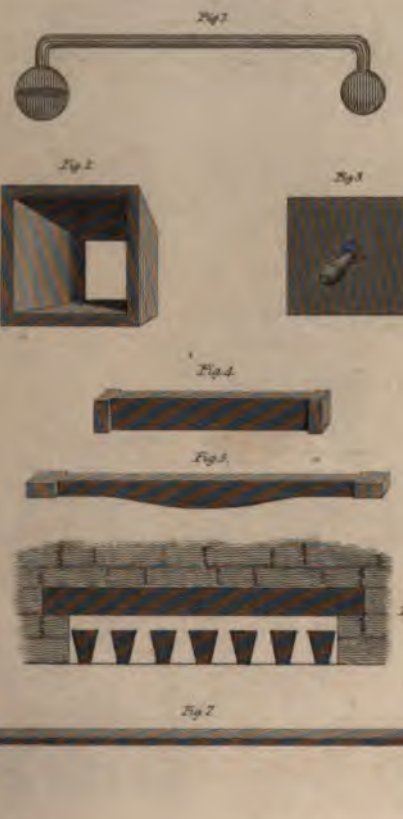
Improved Rum Still.

Fig. 8.



A. The Still ..... B. Preparing Vessel .....
C. Perpendicular Flue ..... D. The Chimney .....
b. The Man hole ..... c. The Safety valve .....
d. The Steep cock to cut off the communication.

Plate VI.



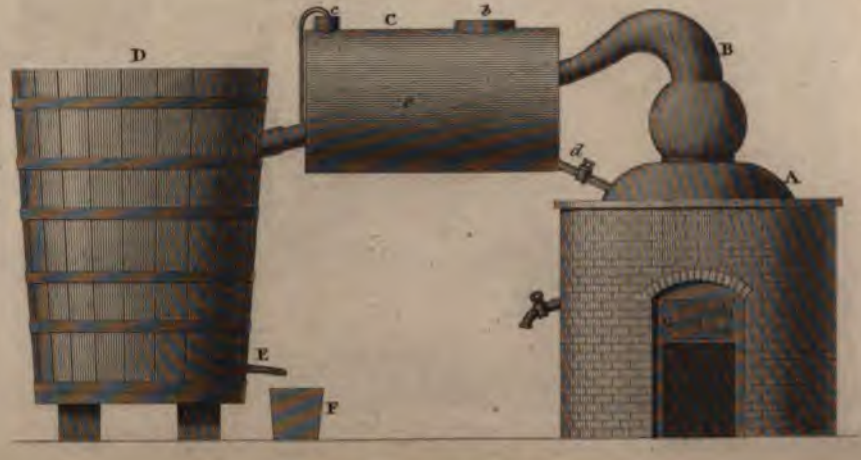
J. Barlow del. — Del. Davis sculp.

Fig 1 A Cryophorus. 2 Iron Hopper.
3 Iron Stopper. 4 Furnace bar.
5 An Improved bar. 6 Furnace fireplace.
7 A binding bar for a large furnace.

ECONOMICAL STILL.

Plate VII.

A. The Still.
B. Still Head.
C. Condenser.
D Worm Tub.
E. The Worm.



b. Man hole.
c. Safety valve.
d. Stop Cock.
e. Pewter pipe.
F. Receiver.

Engraved by J. Harris for Parkes's Chemical Essays.

CHEMICAL ESSAYS.

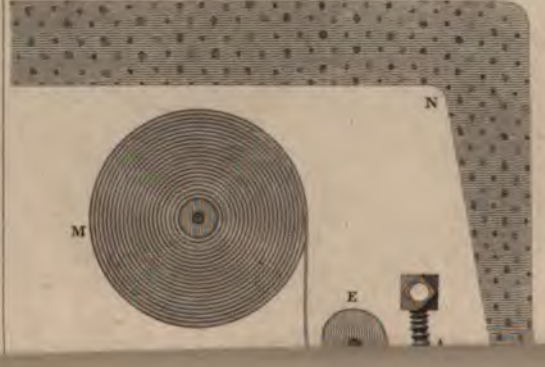
Plate VIII

S. Parkes del. Jos. Davis sculp.

1 An Areometer
2 Hydrostatic Balance
3 Water Jar
4 Cube of Glass
5 Set of Carat Weights
6 Knights Gravity Box
7 Knights Gravity Bot.
8 A Peculiar Stopper
9 Nicholsons Bottle
10 Parkes's D.°

PARKES's CHEMICAL ESSAYS

Plate IX.



Mr. Adam Parkinson's Machine for Printing three Colours at once on Calicoes.

CHEMICAL ESSAYS

Plate X.

Fig 11

Fig. 10.
A. Steam Vessels
B. Revolv. Fans
C. Damp Calico
D. Dried Do.

Fig. 11.
A. Colour Box
B. The Sieve
C. Spring for do.
D. Blue stuff

Fig 10

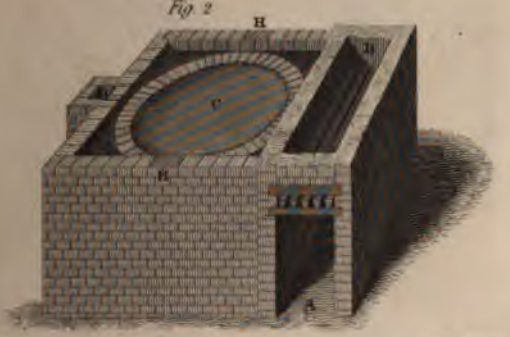
Calico Printing

Plate XI

A Barytes Furnace

Fig. 1

Fig. 2



Jas. Basire sculp.

1 Elevation — 2 Inter.r of Furnace

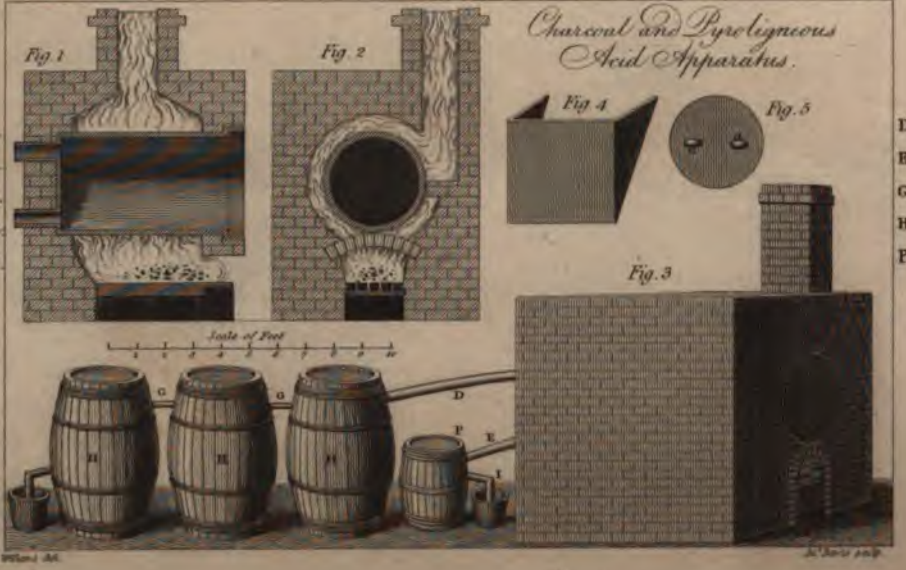
A. Ash pit ..... F. Furnace Arch .....
B. Fire place ..... G. Fire hopper .....
C. Place for the Cauk .... I. Arch of fire place .....

CHEMICAL ESSAYS.

Plate XII

Charcoal and Pyroligneous Acid Apparatus.

1. Cylinder.....
2. Diff.t Section.
3. Elevation.....
4. Outer Stopper.
5. Inner Shut.r



D. Acid Pipe.....
E. Tar Do.....
G. Adapters.....
H. Acid Casks.
P. Tar receiver.

Plate XIII

Coke Oven

Fig. 1

Fig 1 Ground Plan
A Oven floor
B Door way
C Oven wall
D Wall of stone

Fig. 3

Fig 2 Elevation
c Oven floor
D Height of wall
E Door way
G Roof of oven

Fig. 2

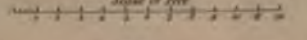
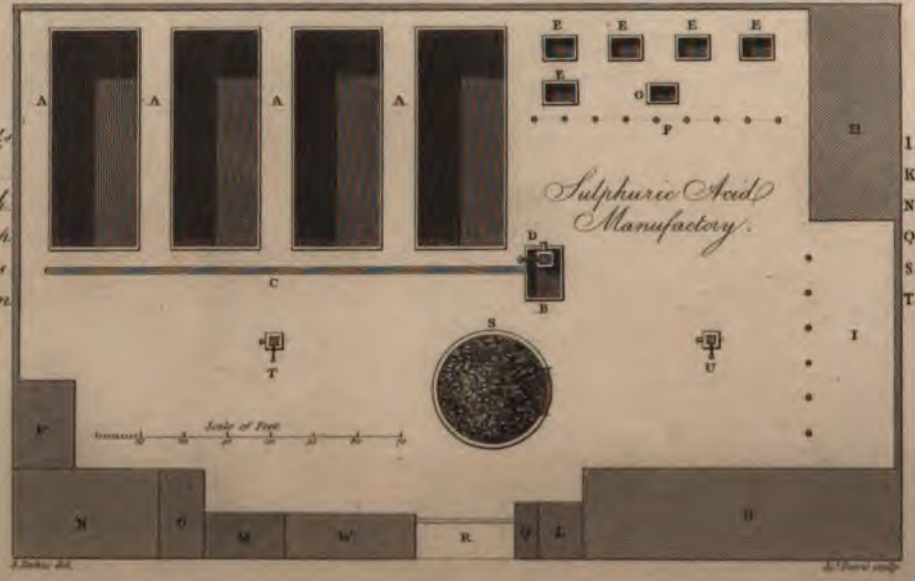


Fig3. New Method of Burning Coals into Cokes.

CHEMICAL ESSAYS.

Plate XIV



ESSAY I.

ON

THE IMPORTANCE AND UTILITY

OF

CHEMISTRY

TO

THE ARTS AND MANUFACTURES

OF

THE BRITISH DOMINIONS.

ESSAY I.

ON

THE IMPORTANCE AND UTILITY

OF

CHEMISTRY.

THE discovery of the loadstone and its important application in the construction of the mariner's compass were the means of producing a general intercourse among nations. The subsequent invention of printing[1] occasioned a rapid progress in that ci-

[1] The mariner's compass was discovered early in the fourteenth century by Flavio Gioia of Amalfi in the kingdom of Naples. Printing with metallic types was invented by Peter Scheffer of Mentz in the year 1450: but it is probable, that printing with separate wooden types had been practised seven or eight years earlier. See the preface to Ames's *Typographical Antiquities*, vol. i. 4to. 1785.

"The storied pyramid, the laurel'd bust,
The trophied arch had crumbled into dust;
The sacred symbol, and the epic song,
(Unknown the character, forgot the tongue,)
Till to astonish'd realms Papyra taught
To paint in mystic colours Sound and Thought,
With Wisdom's voice to print the page sublime,
And mark in adamant the steps of Time."

vilization which had thus been much promoted by the increase of commerce, and by the consequent interchange and general dissemination of the useful arts.

These arts consisted, however, of mere traditional processes which had been communicated, like the secrets of the alchemists, from generation to generation, without science, or any theory on which the true knowledge of them might be founded; nor was it until Lord Bacon had shown the necessity of interrogating nature by experiment, that any rational system of philosophical inquiry was pursued or promulgated.

This illustrious philosopher was indeed the first writer who seems to have had a just view of the character and labours of the Alchemist. By showing how little can be done by reasoning on the works of Nature, until a mass of facts is obtained by experiment, he benefited the world more than a host of his predecessors had done by their conjectures and conceits.

From this period, however, general science made rapid advances in improvement; and if one branch be more indebted to this great but unfortunate philosopher than another, it unquestionably is that of Chemistry, which has eminently availed herself of his grand precept, and continued her unremitting researches until nothing will now satisfy the curious inquirer, but plain facts and lucid deductions from experiment or analogy.

In this state of the public mind, what can be expected throughout Europe but a rapid succession of

improvements in the arts and manufactures, and in the personal comforts and conveniences which are so much dependent on chemical knowledge? Hence it appears desirable, that every individual employed in the superintendance of a manufactory should become acquainted with the general principles of Chemistry, in order that he may more successfully apply the great truths of this important science to the various processes which may at any time require his direction.

With this view I cannot but conceive that very important benefits would accrue to these kingdoms, if Chemistry were made a regular branch of education; and I have imagined that I should render an acceptable service to society by showing the advantages which result from the acquisition of this kind of knowledge; for, until its utility be demonstrated to a large proportion of the community which is not yet apprized of its real value, that general attention to it which it deserves cannot be expected.

It would, however, be no difficult matter to prove that the world might derive great advantages even from the diffusion of a *theoretical* knowledge of Natural philosophy and chemistry. An instance or two will place this assertion in a clear point of view. Two thousand years ago Archimedes[2] was ridiculed for his attention to mathematics and the abstruse

[2] There is no evidence that Archimedes had any knowledge of chemistry; for although the transmutation of metals was attempted three or four hundred years after Christ, Geber, who was a Greek physician of the eighth century, was the first chemical writer whose works were of any value.

sciences; yet by this knowledge he was enabled to invent such mechanical engines as were sufficient to resist the whole Roman army.

To how many accidents is the general of an army or the admiral of a fleet liable, if he have not a comprehensive knowledge of the laws of nature! Julius Cæsar himself relates, that his army was so dismayed on approaching our shores, at the ebbing of the sea from their vessels, supposing it to have been occasioned by a stratagem of the native Britons, that the circumstance had nearly occasioned his total overthrow. In like manner, if Hannibal, the Carthaginian general, had not been acquainted with the effect of acetous acid on calcareous earth, the crag of rock which obstructed the passage of his army through the Alps, would in all probability have remained an insurmountable obstacle.

Not that it can for a moment be believed that he applied the solvent to the whole mass of rock; but, as appears from the account given by Livy, that he merely poured the acid into certain crevices in the limestone; and that after this, the soldiers by means of iron instruments readily broke down a part of what had stood in their way, and thus obtained a sufficient opening for the passage of the grand army.

A further proof of the importance of the dissemination of useful knowledge may be taken from the construction of the *Steam Engine*. Mr. Watt often acknowledged that his first ideas on this subject were acquired by his attendance on Dr. Black's *Chemical* Lectures, and from the consideration of

his theory of latent heat and the expansibility of steam.

This is certainly a remarkable instance of a great national advantage resulting from the establishment of chemical lectures, for the dissemination of philosophical principles; and it is most assuredly very desirable that every subject connected with the trade of the country should also be treated of publicly, and that a considerable number of ingenious men, properly qualified, would follow the example of Dr. Bancroft, but on a more extended scale, and teach the philosophy of manufactures, as he has taught "the philosophy of permanent colours;" or, like Professor Farish of Cambridge, and Dr. Ure of the Andersonian Institution in Glasgow, illustrate the various manipulations by familiar lectures, popular descriptions of processes, and working models of machinery.

The celebrated Tycho Brahe not only attended to the motions of the planets, but to the experiments of his laboratory also, in which he worked upon minerals by means of fire. The great Sir Isaac Newton too, when resting from his immense labours, was wont at times to relieve his mind in the same way, and employed himself occasionally in superintending chemical operations.

The well-informed people of France are now so satisfied of the importance of chemical knowledge, that chemistry is already become an essential part of education in their public schools.—It shall be my business in this place to endeavour to demon-

strate it to be of *equal* importance to the various classes of our countrymen, that the science should be cultivated with the same ardour in these kingdoms.—The science which I now recommend to public notice, has for its object every substance of the material world, and therefore is equally interesting to every civilized nation upon earth.

Were I addressing myself to the father of a family, I would say,—Is your son born to opulence,—is he the heir to an extensive domain; make him an analytical chemist, and you enable him to appreciate the real value of his estate, and to turn every acre of it to the best account[3]. Has he a barren tract of country, which has been unproductive from generation to generation; he will then carefully explore it for hidden treasures, and will probably not explore it in vain. By analysing the minerals which he discovers, he will ascertain with facility and exactness what proportion of metal they contain, and which of them may be worked to advantage[4]. Thus he will operate on sure grounds, and be prevented from engaging in expensive and unprofitable undertakings.

Chemistry will teach him also how to improve

[3] Dr. Home, of Edinburgh, was one of the first writers who attempted to apply a rational theory of chemistry to the improvement of Agriculture.—See his treatise on *The Principles of Agriculture and Vegetation.* Octavo, Millar, London, 1758.

[4] Most of the solid substances which encircle our globe are compound bodies, formed by chemical combinations; it must therefore require some skill in chemical operations to be enabled to decompound them with certainty.

the *cultivated* parts of his estate; and by transporting and transposing the different soils, he will soon learn some method by which each of his fields may be rendered more productive [5].

The analysis of the soils will be followed by that of the waters which rise upon, or flow through them; by which means he will discover those proper for irrigation [6]; a practice the value of which is sufficiently known to every good agriculturist [7].

Should he himself occupy the farm, and become the cultivator of his own estate; he must of necessity be a chemist, before he can make the most of his land, or put it into a high state of cultivation, at the smallest possible expense. It will be his concern not only to analyse the soils [8] on the different parts of his farm, but the peat, the marle, the lime, and the other manures must be subjected to experiment, before he can avail himself of the advantages which they possess, or before he can be certain of producing any particular effect by their means. The necessity of analysis to the farmer is evident from a knowledge of the circumstance, that some kind of

---

[5] See Lord Dundonald's treatise on *The intimate Connection of Agriculture and Chemistry*, page 52.

[6] According to Dr. Home, hard water promotes the growth of plants in a much greater degree than soft water.

[7] The best paper which I have seen on the subject of irrigation is by the Rev. T. Wright, small 8vo. Scatcherd and Co. 1789. This short essay is deserving the attention of every practical farmer.

[8] In the second volume of *The Memoirs of the Imperial Academy of Sciences at Brussels*, quarto, 1780, is an ingenious Chemical Essay of 117 pages, by Mons. De Beunie, on Soils, and more particularly on the Cultivation of Heaths.

lime is really injurious, and would render land which had been hitherto very productive, actually sterile[9].

I allude here to the magnesian limestone, which is common in many districts in England, particularly at Breedon in Leicestershire, where the calcareous earth contains 50 per cent. of magnesia. But, as the Earl of Dundonald has remarked, such lime will be extremely useful on what are called sour soils, or such as contain sulphate of iron, from the decomposition of martial pyrites, as the magnesia will unite with the acid of that salt and form sulphate of magnesia, (Epsom salt,) which greatly promotes vegetation.

Besides, a knowledge of the first principles of chemistry will teach him when to use lime *hot* from the kiln, and when *slacked;* how to promote the putrefactive process in his composts [10], and at what period to check it, so as to prevent the fertilizing particles becoming effete, and of little value. It will also teach him the difference in the properties of marle, lime, peat, wood-ashes, alkaline salt [11], soap waste, sea water, &c., and, consequently, which

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[9] Experiments on the nature of this sort of lime will be found in Professor Tennant's paper in the *Philosophical Transactions* for 1799. See also Darwin's *Phytologia,* page 211.

[10] The Earl of Dundonald has remarked, that "vegetable putrefaction can take place only when attended with air, moisture, and a due degree of heat. Water is then decomposed—vital air absorbed—heat disengaged—and new combinations formed."—*Treatise on Agriculture,* quarto, London, 1803, page 28.

[11] Dr. Home in the year 1758 published a valuable treatise on this subject. Indeed he was the first person that we know of, who made direct experiments on the fertilizing properties of saline matters.

to prefer in all varieties of soil. A knowledge of the chemical properties of bodies will thus give a new character to the agriculturist, and render his employment rational and respectable [12].

Are you a practitioner of MEDICINE, and have you acquired great and deserved reputation in your profession,—if you are not a chemist, you must recollect many painful disappointments, and must have witnessed very unexpected results from the effects of medicine, when you have administered two or more powerful remedies in conjunction [13]. A slight knowledge of chemistry would have informed you that many of the formulæ in the Pharmacopœia, which are salutary and efficacious, are rendered totally otherwise, not to say often destructive, if given with certain other medicines. Many instances of these chemical changes might be adduced, but one will suffice. Mercury [14] and chlorine have both been administered by medical men; and *separately*, either of them may be taken in small quantities, without

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[12] Lavoisier cultivated 240 acres of land in La Vendée on chemical principles, in order to set a good example to the farmers; and his mode of culture was attended with so much success, that he obtained a third more of crop than was procured by the usual method, and in nine years his annual produce was doubled.—Lalande's *Life of Lavoisier*.

[13] Boerhaave, more than a century ago, wrote a treatise to show the importance of chemistry to the medical profession, under the title of *De cognoscendis et curandis Morbis*.

[14] Paracelsus, who lived in the sixteenth century, was, I believe, the first who attempted the improvement of pharmacy by the introduction of the metallic oxides. Philip of *Sides* had, indeed, in the fifth century, produced what he called the tincture of Indian iron, but there is no proof that this ever came into general use.

any injury to the animal economy: but if these substances should be given *in conjunction*, the most dreadful consequences might ensue, as the product of this mixture (*corrosive sublimate*) is a most active and powerful poison.

If the profession of medicine be your son's choice, charge him, when he shall walk the hospitals, to pay particular attention to the Lectures on Chemistry, and to make himself master of the component parts of the different salts [15], and of the chemical affinities which subsist between them and the various articles with which they are generally employed. This will inspire him with professional confidence; and he will generally be as sure of producing any particular chemical effect upon his patient as he would if he were operating in his own laboratory. Besides, the human body is itself somewhat analogous to a laboratory, in which by the varied functions of secretion, absorption, &c., composition and decomposition are perpetually going on: how, therefore, can a medical man ever expect to understand animal physiology, so necessary in the practice of physic, if he be unacquainted with the effects which certain causes chemically produce? Every inspiration we take, and every pulse that vibrates within us, effects a *chemical* change upon the

[15] So ignorant were the professors of medicine of the nature of the salts, that no longer ago than the year 1765 there was a public dispute between the celebrated Margraff and Mons. De Machy respecting the base of the *super tartrite of potash*, whether or no it was an alkali. See *The History of the Royal Academy of Sciences at Paris, for the year* 1765.

animal fluids [16], the nature of which it requires the acuteness of a profound chemist to perceive and understand [17]. Neither can a physician comprehend the nature of the animal, vegetable, or mineral poisons without the aid of chemistry. Many thousand lives have been lost by poison, which might have been saved had the physician been in possession of the knowledge which he may now acquire by a cultivation of chemical science. And though the operation of many of the poisons upon the system be in these days well understood, nothing but a knowledge of chemistry can enable the practitioner to administer such medicines as will counteract their baneful effects. A circumstance which came within my own knowledge, will sufficiently exemplify this position.

In the year 1805, an apothecary in one of the northern counties having drunk some bottled porter was seized with symptoms which convinced him that he was poisoned; but not knowing what noxious matter he had taken, and being incapable of analysing the remainder, no antidote could be applied, and he gave himself up as lost. A physician had been called in: but neither he nor the patient, nor his partner, could get any information by examining the remaining contents of the fatal bot-

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[16] The use of the blood in respiration was first demonstrated by Priestley. See his paper, which was read to the Royal Society the 25th January 1776, and printed in the *66th volume of their Transactions*, page 226.

[17] Mr. Professor Brande has written an interesting and very original paper on the colouring matter of the blood. See *Philosophical Transactions* for 1812, page 90.

tle; though, I understand, they are all intelligent men, and in great repute in their profession. In this dilemma what could be done? It was recollected, however, that a neighbouring gentleman had the reputation of being a good chemist. To him the physician and the partner of the patient hastened, to get the dregs analysed, and to learn what ought to be administered. Fortunately, this gentleman had just received Göttling's Book of Tests, which I had procured for his brother, and which had been sent to him but a very short time before. By this book he was enabled to ascertain that the poison was oxide of antimony: and when the patient was informed of it, he recollected that antimonial wine had been kept in a similar bottle some years before; and supposed that the porter must have been bottled without the dregs being properly washed out. This circumstance led to the proper antidote, which was administered immediately; and the life of the unfortunate man was preserved: but, in consequence of the loss of time, the poison had so far taken possession of the system as to deprive him of the use of a limb.

If we look to the national MANUFACTURES, there is scarcely one of any consequence that does not depend upon chemistry, for its establishment, its improvement, or for its successful and beneficial practice;—though, in order to see the real connexion which subsists between chemistry and the arts, it will be useful to take a short view of the principal trades which are carried on in these kingdoms.

One of the staple manufactures of the country is that of IRON: and it will be found that, from the smelting of the ore to its conversion into steel, every operation is the effect of chemical affinities [18]. In the first place, it requires no small share of chemical knowledge, to be able to appreciate the *value* of the different ores, and to erect such furnaces for their reduction as may be contrived in the best possible manner for facilitating their fusion, and for producing good pig-iron. The subsequent processes, to convert the crude metal into malleable iron, are also entirely chemical, and will be conducted to the best advantage only by those who have acquired a scientific knowledge of the changes which take place in these operations.—The making of CAST STEEL, which has been kept so profound a secret, is now found to be a simple chemical process, and consists merely in imparting to the metal a portion of carbon, by means of fusing it in crucibles with carbonate of lime, or by cementation with charcoal powder, in a peculiar kind of furnace constructed for that particular purpose.

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[18] Since much valuable iron-ore is raised in districts where charcoal is not to be procured, the proprietors of such mines are generally under the necessity of using coke, which produces iron of a very inferior quality. It is therefore become a desideratum to coke pit coal so as to give it the properties of charcoal; and I think it probable that with some kind of coal this might be effected. The coke which most resembles charcoal of any that I have seen is made at the Duke of Norfolk's works near Sheffield. For a particular description of his furnaces, and of the method of managing them, see the *Chemical Catechism, Additional Notes*, No. 50.

Some of the steel-works in the North have these furnaces extremely large, and I have been told that the increase in weight which the iron acquires from the carbon to convert it into steel is amply sufficient to defray all the expenses of fuel and attendance. The German steel is made directly from cast iron, and this is effected merely by forging the crude metal only to a certain point.

The ancients, it is believed, had some peculiar method of making steel. This suspicion is grounded on the hardness of some of their statues, as well as on the nature of the Egyptian obelisks, which are carved with a variety of figures, and yet are made out of porphyry that resists the tools of modern times. Dr. Lister (in a paper read before the Royal Society) complains that this valuable secret is now lost. According to Aristotle and Pliny, the ancient steel was made by keeping forged iron for a certain time in melted cast iron [19].

The manufacturers of *chemical utensils*, and other articles too various to be enumerated, in cast iron (called IRON-FOUNDERS) will also acquire some valuable information by the study of chemistry; as it will teach them how to mix the different kinds of metals; how to apportion the carbonaceous and calcareous matter; and how to reduce the *old* metal, which they often receive in exchange; many hundred tons of which are annually sent away as ballast for ships, for want of that knowledge which

[19] See Lewis's *Notes on Neuman's Chemistry*, vol. i. page 116.

would enable them to convert it into good saleable iron. Indeed, before the smelting of ores was properly understood, great part of the iron was not extracted in the first instance, but was thrown by with the dross; and I have understood that there are heaps containing many thousand tons of such scoria now lying in the forest of Dean, in the county of Gloucester, so rich in iron that the proprietor finds it his interest to work the same over again.

In like manner the founder of printers' types has derived great advantage from a knowledge of the methods of reducing metallic oxides. In this trade fires are kept under the pots the whole day, to preserve the metal constantly in a melted state; the consequence of which is, that the metal at the surface perpetually oxidizes and must be frequently removed. Formerly these skimmings were called *dross*, and were thrown away as of no value. At length an individual made an experiment upon them, and at this day every manufacturer knows how to convert this refuse into good useful type-metal: so that a large manufacturer will now annually recover from three to four tons of metallic alloy, worth at least 100*l.* per ton, from these skimmings.

When we consider the WOOLLEN, the COTTON, and the CALICO manufactures, how great is the importance of each of these trades to the British dominions! To preserve these sources of national wealth, the utmost attention must be paid to the beauty, the variety, and the durability of their seve-

ral colours. Now of all the arts, none are more dependent upon chemistry than those of DYEING[20] and CALICO-PRINTING. Every process is chemical; and not a colour can be imparted, but in consequence of the affinity which subsists between the cloth and the dye, or the dye and the mordant which is employed as a bond of union between them. It is then surely evident how valuable a chemical education must be to that youth who is designed for either of these trades, and how necessary is that portion of knowledge which shall enable him in a scientific manner to analyse his different materials, and to determine the kind and the quantity necessary for each process. After all, his colours will be liable to vary, if he do not take into the account, and calculate upon, the changes which take place in them by the absorption of oxygen[21]; a knowledge of which, and of the different degrees of oxidizement which the several dyes undergo, requires no small share of chemical skill: and yet this skill is absolutely necessary, to enable either the dyer or the calico-printer to produce in all cases permanent co-

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[20] The first account of dyeing that we have in the English language was written by Sir William Petty, at the desire of the Royal Society, entitled "An Apparatus to the History of the common Practices of Dyeing." A copy of this piece may be seen in the Bishop of Rochester's *History of the Royal Society*, quarto, London, 1667, page 284.

[21] On this subject some valuable information may be found in Fourcroy's *System of Chemistry*, vol. viii. pages 70-78.—Berthollet's *Elements of the Art of Dyeing*, vol. i. pages 45—65, and in a memoir "*On the Coloration of Vegetable Matters by Vital Air*," in the 5th tom. of *Annales de Chimie*, pages 80—91.

lours of the shade which he intends. Moreover, these artists must be indebted to chemistry for any valuable knowledge which they may acquire of the *nature* of the articles they use in their several processes; not to say that they are wholly dependent upon this science for the artificial production of their most valuable mordants[22], and for some of their most beautiful and brilliant colours. An instance or two will render this evident.

Formerly a calico-printer required many weeks to produce a printed cotton with some colours, such as an olive ground and yellow figures; a scarlet pattern on a black ground; or a brown ground with orange figures: but, by means of chemical preparations, the whole of this work may now be done in a few days; patterns more delicate than ever, may be produced; and all with a degree of certainty of which former manufacturers had no idea, the system being now entirely altered. According to the former practice, the mordant[23] was first applied to those parts of the cloth that were intended to be olive, brown, or black; it was then necessary for the piece to remain some time before it could be dyed, and afterwards to be exposed in a bleaching-ground a sufficient time to clear those places from the colour-

[22] Dr. Bancroft is of opinion that the ancient Ægyptians employed some of the mordants now in use, and that they were indebted to alum and iron for producing those effects mentioned by Pliny, l. xxxv. § 42.

[23] For an explanation of the action of mordants, see Berthollet *On Dyeing*, vol. i. chap ii. page 28; or Bancroft *On Permanent Colours*, chap. vii. page 167.

ng matter of the dye which had not been acted upon by the mordant: a different mordant was then applied by the pencil; and it was necessary to pass the whole piece through the dyeing copper a second time, in order to give the desired colour to those particular parts, and finish the pattern.

Now, all these effects are produced by dyeing the cloth a self colour in the first instance, and afterwards merely printing the pattern with a chemical preparation, which discharges a part of the original dye, and leaves a new colour in its stead. Thus a brown may be changed in an instant to an orange; a dark olive to a yellow; or a black to a bright scarlet. In consequence of similar improvements, rich chintz patterns, which formerly required two years or more to be completed, are now commonly finished in a few weeks.

Again,—it was not known how to dye wool of a perfect scarlet till the preparation of the nitrate of tin was discovered by a foreigner. Cornelius Drebbelius of Alcmar in the United Provinces, a man in great esteem with King Henry VIII., made this important discovery; and having left in writing a particular method of making this mordant and of its application in dyeing, Kuster, or Kustelaer, his son-in-law, brought it to England, and about the middle of the 16th century settled as a dyer, at Bow, near London, where he acquired considerable emolument[24].

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[24] See Dallow's *Boerhaave*, quarto, 1735, vol. i. page 58.

The art of BLEACHING[25], which is so intimately connected with calico-printing and dyeing, has also received such improvements from the science of chemistry, that no man is now capable of conducting it to the best advantage, without a knowledge of the real principles on which the present practice is established.

The manufactures of EARTHENWARE[26] and PORCELAIN[27], which were so much improved and extended by the ingenious and indefatigable Wedgwood, and which are become by his means a source of national wealth, and give employment to thousands of the community, are in like manner dependent upon chemistry for the successful management of all their branches, from the mixture of the materials which form the body of the ware, to the production of those brilliant colours[28] which give a va-

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According to Dr. Sprat, Drebbelius was a chemist, and not a dyer. *Hist. Roy. Society*, page 391.

[25] The person who has written the largest on this subject is Charmes; his book was translated by Mr. Nicholson into the English language, and was published by Robinsons, 1799, 8vo. pp. 351, with many plates of apparatus, &c.

[26] Dibutades, a potter of Sicyon, first formed likenesses in clay at Corinth, but was indebted to his daughter for the invention. The girl, being in love with a young man who was soon going from her into some remote country, traced out the lines of his face from his shadow on the wall by candle-light. Her father filling up the lines with clay formed a bust, and hardened it in the fire with the rest of his earthen-ware.—Athenag. *Apolog.* p. 19. edit. H. Steph. 1557.—*Pliny*, book xxxv.—See Bergman's *Essays*, vol. iii. p. 58.

[27] Porcelain was made by the Chinese and Japanese some hundred years before it was manufactured in Europe. No china was made in this quarter of the world before the beginning of the eighteenth century.

[28] An account of the respective colours which the different

lue to the manufactures by their permanency and beauty.

Mr. Wedgwood was so sensible of the importance of chemistry to these arts, that he not only applied to the study of the science himself, but, upon the death of the celebrated Dr. Lewis (author of the Commercium Philosophico-Technicum), he engaged his assistant, a Mr. Chisolme, to experimentalize with him, and to devote his whole attention to the improvement of the manufacture by the application of his chemical knowledge, of which perhaps few men in the kingdom at that time had a larger share. A faint idea of the advantages which he derived from these sources may be conceived from the following circumstance:—Dr. Bancroft, in his "Philosophy of Permanent Colours," when treating on iron, says, "I remember having been told by Mr. Wedgwood, that nearly all the fine diversified colours applied to his pottery were produced only by the oxides of this single metal." This one fact is sufficient to show with what assiduous application he must have studied chemical science, and how insufficient every attempt to bring his manufacture to the perfection which it has now attained, would have been, without this attention.

The sister art, that of making GLASS, is also entirely chemical, consisting in the fusion of siliceous earth with alkali [29] and the oxides of lead [30]. In this

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metals produce on porcelain may be seen in the xiiith vol. of the *Philosophical Magazine*, page 342; and vol. xiv. page 17, &c.

[29] It has of late years been discovered that sulphate of soda

trade, as well as in many others, the chemical manufacturer, and the man of enlightened experience, will have many advantages[31]. He will not only know how to analyse his alkalies and to ascertain their exact value before he purchases them, but he will be enabled on chemical principles to ascertain the exact quantity necessary[32] for any fixed portion of silica, which, to those who are ignorant of our science, must always be a matter of uncertainty, and must repeatedly subject them to losses and disappointment.

The TANNING OF HIDES[33] also is a process which was formerly carried on by persons who merely followed a routine of operations, to which they had been accustomed, without knowing the real cause of any of

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may be applied to the purpose of making best flint glass, which opens the prospect of a very considerable saving in this manufactory. See an account of some experiments in Nicholson's *Journal*, vol. xxxi. page 357.

[30] In the reign of the Emperor Nero, glass was so scarce at Rome that two small cups made of it sold for the immense sum of six thousand sesterces.—*Pliny*, l. xxxvi. c. 26.

[31] Since it has been understood how to apply the oxides of metals so as to produce various permanent colours in vitrifiable substances, some ingenious workers in glass have been enabled to produce several curious imitations of many of the gems and precious stones. The works of Neri and Blancourt contain the best directions we have at present in print on this subject.

[32] It has been said, that in the time of Tiberius it was known how to make glass malleable; but the truth of this is, I think, doubtful: they had anciently a manufactory of glass in the Isle of Lesbos.

[33] There can be no doubt but that leather was prepared in times of remote antiquity; for the contemporaries of Moses not only tanned leather, but knew also how to colour it. *Skins dyed red* are often mentioned in the sacred books. Pliny attributes the invention of leather to Tychius of Bœotia.

the changes produced. It has now, however, been well ascertained that the whole art consists in impregnating the animal matter with that peculiar principle taken from the vegetable kingdom, called *tan* (or *tannin*), the effect of which may be explained entirely on chemical principles. It is also now known that many substances, besides oak bark, contain tan; and to chemistry we are indebted for the means of discovering with accuracy the *quantity* of tan which the several astringent vegetables contain. Besides, this principle having been formed *artificially* by a modern chemist[34], it is not improbable, that, whenever these manufacturers pay a proper attention to the science we recommend, they may be able to direct us how to prepare for them, in our laboratories, the article in question, so as entirely to supersede the use of oak bark. This would be an event of great national importance, as the demand at present is so great, that it is not only imported from the continent, but trees, it is well known, have been actually cut down on purpose for the bark. Should the chemical tanner not be fortunate enough to make a discovery of the kind just mentioned, he will at least be able to analyse the substances now in use, and to appreciate their *relative* value; a matter of no small moment to a man who operates

[34] This refers to a discovery made by Mr. Hatchett, an account of which is detailed in the *Philosophical Transactions*, vol. xcv. for the year 1805, pages 211 and 285, and in vol. xcvi. for the year 1806, page 109. Some valuable remarks by Sir H. Davy on the process of tanning leather are given in the *Journals of the Royal Institution*.

upon a large scale. And it is not impossible but he might discover some way of employing to advantage the several refuse articles which a tan yard produces, and which are now put aside as of no value[35], Chemistry will enable him also to combine the tanning principle with the skins, so as to form leather the most impervious to moisture; and to give the hides the greatest increase of weight in the least possible time:—and these are the main secrets on which the profit of the trade chiefly depends[36].

The property which tan has of combining with gelatine, and therewith forming an insoluble precipitate, may be applied to the important purpose of purifying rancid fish oil. I once knew a gentleman who fitted up a very complete apparatus with this intention; and by agitating the oil with the tannin and water in a large vessel, to which he gave a rotary motion, the tannin became intimately combined with the gelatinous impurities, and then completely subsided. By this means the oil, which was fit only for

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[35] The old tan which is thrown out of the tan-pits was considered to be of no use until the arrival of King William III. in this island. He had observed that it was employed in Holland for raising orange trees, and he introduced the use of it here for the same purpose. It has since been brought into general use, and is now in great estimation with most of our gardeners; the great and continued heat which it produces renders it proper for every species of forcing.

[36] The revenue arising to Government from the impost on tanned leather in Great Britain is upwards of two hundred thousand pounds per annum. An ample account of Seguin's improved processes is given in Nicholson's *quarto Journal*, vol. i. pages 271—279. There is also a memoir by Proust, on the Tanning Principle, in the *Annales de Chimie*, tom. xxv. page 225.

burning in the street lamps, was rendered free from smell, nearly equal to the best spermaceti oil, and fit for burning in the closest chambers.

Some of the manufacturers of MOROCCO LEATHER, an article nearly new as a production of this country, have the utmost reason to regret the want of chemical knowledge.—Until within these few years, the consumers of morocco depended entirely on a foreign supply, many fruitless attempts having been made to prepare the article in this country. Later trials, with various chemical mordants, have, however, so far succeeded, that several manufactories have been established in the metropolis, within the last twenty years, where the most beautiful moroccos are now prepared at prices which have superseded the necessity of all foreign importation. The reds and yellows are the principal colours for morocco leather, and in these our manufacturers were very deficient, till a Mr. Philippo, a native of Turkey, introduced the eastern mode of management, for which he received the gold medal and 100*l.* from the Society for the Promotion of Arts, Manufactures and Commerce. Since then we prepare this leather in a manner much superior to any that can be brought from abroad, and large quantities of it have been exported to foreign markets [37]. Notwithstanding this, some colours are still produced by our manufacturers in a tedious and ex-

[37] *Transactions of the Society of Arts, Manufactures and Commerce*, vol. i. page 18.

pensive way:—a series of well-conducted and appropriate chemical experiments would no doubt direct them to prepare the same colours, with greater certainty, and by a more economical process.

The manufacture of SOAP[38], an art of considerable importance, and which materially aids the revenue of the country, has in general been conducted, like many of the foregoing, without any regard to system: and yet, perhaps, there is no manufacture which can be benefited in such various ways by chemistry as this. To those who are designed for this trade I have no hesitation in recommending the study of the science as a matter of the first importance[39]. Many thousands per annum, now lost to the community, would be saved, if the trade were universally carried on upon scientific principles. Make a soap-boiler a good chemist, and you teach him how to analyse barilla, kelp, potass, &c., so as to ascertain the proportion of alkali in each,—the

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[38] The first notice we have of soap is by one of the Hebrew writers: "Though thou wash thee with nitre and take much *soap*, yet thine iniquity is marked before me." *Jeremiah* ii. 22. Ætius, who flourished about the end of the 4th century, and was the first Christian medical writer, speaks of a black soap; and Paulus Ægineta, a Greek physician, who lived in the early part of the 7th century, says he made an extemporaneous soap from oil and the burned dregs of wine.

[39] The Government of France considered the manufacture of soap to be of so much consequence, that in the year 1795 the Committee of Public Safety engaged those celebrated chemists Mons. Darcet, Lelievre, and Pelletier, to investigate the nature of the art, and to endeavour to ascertain how the various processes might be improved by chemical science. Their report is printed at large in the *Annales de Chimie*, tom. xix. pages 253—354.

only sure guide to purchasing with advantage and profit, which with the common manufacturer is mere chance. When these articles are at an exorbitant price, he will have recourse to various residuums, which he will decompose by *chemical* means, and make use of as substitutes. In choosing his tallows, he will learn how to avoid those which contain a large portion of sebacic acid, which require much *more* barilla than good tallow, and yet produce *less* soap. He will know how to oxidize the common oils and oil dregs, so as to give them consistence, and render them good substitutes for tallow,—and how to apportion his lime so as to make his alkali perfectly caustic, without using an unnecessary quantity of that article. He will likewise be aware of the advantage to be derived from oxidizing the soap while boiling. A knowledge of chemical affinities will teach him how, at a cheap rate, to make as good and as firm soap with *potass*, as with the mineral alkali; and how to take up the heterogeneous salts, so as to give the alkali full opportunity of forming a chemical combination with the tallows and other oleaginous matter upon which he may be operating. And lastly, he will know how to make use of the *waste* lyes so as to decompose the salts which they contain, and convert them to good and serviceable alkali, fit for future operations. Some of the manufacturers of soap avail themselves of none of these advantages.

An example of the benefit which may arise to the arts from a chemical examination of the nature of

bodies, may be seen in the employment of the chemical residuums just mentioned, and which were formerly thrown away as useless. The old makers of Glauber's salt regularly threw away the muriatic acid which resulted from the process; and the sulphate of potash, which remains after the distillation of nitrous acid, was formerly thrown into the Thames. Now, these articles are employed in various manufactories, and turn to a good account. I have indeed been told that Mr. Steer, formerly a very large aqua ortis maker at Birstall, near Leeds, was for many years accustomed to lay his glass retorts in a shallow rivulet which ran through his fields, where, in a few weeks, the indurated salt was dissolved, and gradually washed away in the water. By this management he avoided the necessity of breaking the retorts: but from the extent of his business, I am persuaded that the salt thus lost for a number of years would have brought him some thousands of pounds, if it had been preserved to the present time.

The manufacture of CANDLES, which is often connected with soap-making, though it is of comparatively small importance, may yet derive advantages from chemistry, which would repay the study[40].

[40] Candles should be made without any admixture of oil or grease, and when laid up should be preserved from the action of the atmosphere. If tallows are weak, a part soon becomes converted by exposure to the air to an acid, and this renders the whole, when melted together, unfit for candles. I have heard of some persons who were in the habit of keeping their candles closely covered up in bran, and taking them out only as they wanted to use them.

Foreign tallows, which frequently contain a large portion of acid, rendering them inferior to the English, may be purified at a very trifling expense by chemical means; and by the proper application of chemical agents other brown tallows may be rendered beautifully white, and fit for the best purposes.

The mode which naturally presents itself as the best for separating the sebacic acid from tallow, is that of melting it in water containing some alkali; but old tallows may in general be sufficiently purified from their rancidity by melting them upon lime water, and giving a considerable agitation to the whole mixture; for when the water is again suffered to subside, it will be found to be offensive in smell, and to have subtracted most of the impurities of the tallow. Should the tallow, however, be found not to be sufficiently purified, a repetition of this process would completely effect it.

Where great quantities of candles are required, as in large manufactories, mines, collieries, &c. a great saving would arise from the use of carbureted hydrogen gas, which, as the inhabitants of most of our large towns can now testify, produces a beautiful and intense light, much more cleanly [41] than oil or

[41] The person who discovered the inflammable nature of this gas was the Rev. Dr. Clayton, more than seventy years ago; but Mr. Murdoch of Birmingham was the first who applied it to the lighting of apartments, &c. For an account of its management and the economy of employing it, see *Philosophical Transactions*, vol. xcviii. for the year 1808, page 124; or the *Chemical Catechism*, page 457.

tallow, and at little or no expense. Oils and tallows when burnt with a wick generally produce a portion of soot; but this combustible gas is wholly converted into water and carbonic acid gas, and therefore will soil nothing.

A slight knowledge of the mode of managing the gases would enable the proprietor of all such collieries as may be safely entered with a naked candle, to procure this gas from the small coal, which is *trodden under foot*, and to light up his coal-pits with it with the greatest safety, and at NO EXPENSE. If this mode were adopted, the workmen would be lighted much better than they can possibly be by any other means; thousands of pounds would be annually saved to the community; and the many tons of tallow which are now consuming in these subterranean works might be used in the manufacture of soap; which would tend to lower the price of that necessary article, and render our poor more cleanly and comfortable.

The BREWING OF FERMENTED LIQUORS, a trade of considerable and increasing consequence, is altogether a chemical process [42]. To those persons

[42] Isis and Osiris, it has been said, instructed the countries that were destitute of wine, by what methods they might prepare beer from corn. See Cogan's *Diodorus Siculus*, page 9. When Tacitus speaks of the ancient Germans making wine from *corrupted* corn, he referred, no doubt, to a process somewhat similar to English Brewing. Basil Valentine, an eminent chemist who flourished in the beginning of the fifteenth century, wrote expressly on the different methods of brewing malt liquors. For an account of the curious management by which such kinds of beverage were prepared at the time of the Norman Conquest,

whose concerns are so large that it would require a princely fortune to purchase even the *utensils*, it must be surely of the utmost importance to acquire some knowledge of the principles of bodies, and of the nature of those changes which take place in the materials upon which they operate. I would therefore say to such persons, Give your sons a chemical education, and you will fit them for conducting, in the best possible manner, the business which you have established. Hence they will learn how the barley, in the first instance, is converted to a *saccharine* substance by malting [43]; how the fermentative process converts the saccharine to a *spirituous* substance; and how the latter, by a continuation of the process, becomes changed into *vinegar*. The nature of fermentation (which until lately was entirely unknown) will be studied and understood [44]; and they will not only have learnt the means of promoting and encouraging this process, but also how

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the reader may consult *Du Cange Gloss.* tom. ii. page 662. Some good practical directions for brewing malt liquors will be found in Shaw's *Essays*, octavo, 1761, page 73, &c. and in a work by Michael Combrune, entitled *The Theory and Practice of Brewing*, Dodsley, London, 1762.

[43] There is a valuable paper on malting in *The Memoirs of the Literary and Philosophical Society of Manchester*, by Mr. Joseph Collier, vol. v. page 265.

[44] A Memoir on Fermentation by Fourcroy and Vauquelin has been translated for *The Philosophical Magazine*, vol. xxv. page 176, &c. and continued page 219 and the sequel.

An ingenious friend assures me, from his own experience, that if new rum be exposed for a night to a severe frost, and then removed to a heated room, and thus alternately for a week or two, it will in that short time have acquired a flavour equal to fine *old* spirits.

to retard or check it, whenever it is likely to be carried too far; so that the scientific brewer will be as sure of uniformly obtaining satisfactory results, as he would if he were operating on matter by mere mechanical means.

In like manner the DISTILLER [45], the maker of SWEET WINES, and the VINEGAR MANUFACTURER [46], will all receive benefit from the cultivation of the science we are recommending [47]. Till the promulgation of the new chemical doctrines, the making of vinegar was carried on like many other trades, in which the makers themselves had no idea of the nature of their own process [48]. An acquaintance with chemistry will teach them many important matters; particularly how it is that the spirituous fermentation is succeeded by the acetous; and how the liquor acquires the substance necessary to produce this change [49]. When this is once

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[45] When the Romans had possession of this island, the art of distillation was unknown. It is said to have been introduced here in the early part of the reign of Henry II.

[46] Chrysippus, who wrote in the third century before Christ, speaks of the excellence of the Egyptian vinegar. Such was its strength, that it quickly dissolved the finest pearl Cleopatra had in her possession. *Pliny*, ix. 35.

[47] It has been asserted that in wine countries good vinegar may be made in fifteen days. See *Phil. Trans.* vol. v. p. 2003.

[48] An account of the theory of Fermentation must be read and understood, before a manufacturer can know how to conduct this process in a scientific manner. I have seen nothing, however, on the art of making vinegar which is more to the purpose than the directions which were published by Boerhaave nearly a century ago. See Dallow's *Translation*, in 2 vols. 4to. London, 1735, vol. ii. page 143.

[49] When the vinegar is removed from the action of the sun, it

known, they will soon find by experiment how to oxygenize their wash at the least expense, and in the least possible time[50]. Indeed, when chemical knowledge is more advanced, the process which now requires several months will probably be completed in as many days. The adoption of stoves and some other methods, which might easily be devised, would, I am persuaded, occasion a great saving in this manufactory, besides doing away the necessity of exposing the vinegar in the open air to the sun for so many months, as is the present practice, whereby the casks sustain so much injury as to entail a heavy annual expense on the proprietor of every large work for this article alone.

The REFINING OF SUGAR is also a chemical process; every branch of which depends upon laws well known to chemists[51]. The separation of the sugar

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is customary to break up the pipes into small casks and to purchase new wine-pipes to put into their place, from an idea that the *wine* within the wood would add an additional strength to the vinegar; but a knowledge of the cause of the change from the vinous to the acetous fermentation, aided by experience, would inform them that the process will always go on much faster in *old* vinegar casks.

[50] William Homberg, a well known chemist of the seventeenth century, partially filled a bottle with wine that was not at all acid, and having securely corked it and tied it to the vane of a windmill, it became in three days converted into good vinegar. Might not this idea be improved upon, so as to expedite the process in our large manufactories?

[51] According to Dr. Anderson, in his History of the Origin of Commerce, the refining of sugar was not practised in this country until the restoration of Charles II. It is still conducted by Germans, and little or no improvement has been made in any of the processes since that time. The new patent method suggested by M. Cronstat, and for which he required of the

from the molasses; the absorption of the superabundant acid; the granulation of the purified sugar; and the crystallization of candy; will all be conducted most economically, and with the least difficulty, by those who have studied the science with a view to the improvement of their art[52].

The REFINING OF GOLD AND SILVER may appear to be merely a mechanical operation; but even in this trade the artist cannot produce a single effect which is not attributable to the play of the chemical affinities. To obtain the best and most profitable results in the business of parting, it is necessary that the nitrous acid should be prepared for this express purpose. Some refiners may imagine this to be of no consequence; because they purify it, they say, by means of a solution of silver before they use it. But I can assure such refiners that it is impossible to purify *some* aqua fortis, by means of silver water, as it is usually applied; and that, when such aqua fortis is employed, a considerable loss in the produce of the gold is the inevitable consequence. Besides, there is great reason to believe that a considerable portion of silver is often lost in the process which succeeds that of *quartation*, by the blue water being removed to the verditer-vats before the whole of the silver has been precipitated. A know-

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London refiners 50,000*l.*, appears to me to be entirely inapplicable on a large scale.

[52] For an account of a new mode of boiling sugar by means of heated oil, see the last edition of the *Chemical Catechism*, article SUGAR.

ledge of chemical principles would suggest to the refiner a mode by which, without the aid of any apparatus, he might in an instant detect even the tenth of a grain of that metal, if left in the solution.

In like manner the reduction of the ores of COPPER[53], LEAD, TIN, ZINC[54], and ANTIMONY, and the manufacture of BRASS, have all been very materially improved by the application of chemical knowledge, and have supplied sources of wealth to individuals, an immense revenue to the government, and a profitable employment to many thousands of the community.

The manufacturers of GUNPOWDER[55], ALUM[56], COPPERAS, BLUE VITRIOL, and of all other SALTS, would likewise do well to become chemists, before

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[53] The copper mines in Cornwall were worked to great disadvantage until Queen Elizabeth invited one Daniel Houghsetter from Germany to instruct her subjects in the art of managing them. For an account of the exclusive privileges which the Parliament granted him, see *Statutes at Large*, in the reign of Queen Elizabeth.

[54] Notwithstanding the vast stores of Calamine with which this island abounds, we were in the habit of importing all our zinc for the manufacture of brass from India, until Margraaf instructed some individuals in the method of procuring it from this ore. According to Pliny (l. xxxiv.) brass was known to the ancients.

[55] It is a curious fact, that "upon our discovery of China, we found that nation possessed of gunpowder, a composition which could not have been made without a considerable knowledge of chemistry." See the preface to Delaval's *Inquiry respecting Colours*, page 62.

[56] The first alum manufactured in England was in the reign of Queen Elizabeth, at Gisborough in Yorkshire, by one Thomas Chaloner, an ancestor of the present R. Chaloner, Esq. M.P. for the city of York. For some particulars of this intrepid man, see Notes to the *Chemical Catechism*, tenth edition, page 100.

they attempt to bring their several arts to the perfection of which they are capable. The crystallization of salts depends upon so many adventitious circumstances, that no small share of knowledge is necessary to enable a manufacturer at all times, and in all seasons, to produce the article he intends. Until within these few years the MAKERS OF ALUM bought alkalies of every description. An accurate analysis of alum has now discovered that potash and ammonia are the only alkalies which enter into the composition of alum; and consequently, that during a long series of years large sums have been expended by the manufacturer in the purchase of salts which were comparatively of no use.

The article, however, which is more particularly referred to here, is a refuse product of the soap-works called *black ash*, for which the alum-maker has given from 8*l.* to 15*l.* per ton, though it is composed in a great measure of soda and muriate of soda, neither of which salts is of any use in the preparation of alum. These manufacturers must, surely, have been as careless in their inquiries as the Spaniard of whom Bowles speaks, who on being asked if he knew how the saltpetre was yearly regenerated in his grounds, replied, "I have two fields—in the one I sow wheat, and it grows; in the other I collect saltpetre [57]."

Even science itself is now reaping the benefit of its own discoveries. A few years ago, the MANU-

[57] See Bowles's *Histoire Naturelle de l'Espagne*, page 80.

FACTURERS OF PAPER were apprehensive that it would be impossible to supply a quantity of that article fit for printing upon, adequate to the increasing demand. Necessity, however, often the source of new inventions, had recourse to chemistry; and in this science, of universal application, found the means of improving the colour of the very coarsest materials;—so that rags which formerly would have been thrown by for paper of the lowest description, are now rendered subservient to the progress of truth, and the promulgation of knowledge [58]. And so easy is the application, that an immense quantity of the materials can be bleached in a few hours; and paper sufficient to print a copy of the largest work in the English language may thus be whitened at the expense of only a few pence. These improvements, which, however, are not yet universally practised, will, when chemical science is better understood, probably lead the way to a *cheap* method of bleaching *coloured* rags also, and enable the bookseller to furnish us with the most common works in a style of neatness to which we have not hitherto been accustomed.

In like manner it might be shown that the making of BREAD, SUGAR, STARCH, VARNISH, and OIL OF VITRIOL; the felting and fulling of HATS, the refining of SALTPETRE, and the manufactures of

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[58] This is done by means of chlorate of lime. But I would suggest that no manufacturer should employ it, unless he has an abundant supply of water to wash the pulp frequently and thoroughly after its use.

SMALTS, ULTRAMARINE, PRUSSIAN BLUE[59], COBALT BLUE, CUDBEAR[60], ARCHIL, and other colours[61], are all dependent upon chemistry for their improvement and successful practice:—but the mention of a few particulars must suffice.

The success of the starch manufactory depends, in a great measure, upon giving a proper degree of fermentation[62] to the wheat; it is evident then how much the profit might be increased by a scientific attention to this circumstance.

In making oil-varnishes it is first necessary to oxygenize the oils by means of metallic oxides, in order to give them the drying property. To do this in the best possible way, requires some chemical skill; and, whether the varnish be made with a resin or a gum-resin, it is of the utmost importance to learn

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[59] A large proportion of the Prussian blue which is made in this country goes to China; the captains of the East India Company's ships take it out at the beginning of the year, and it constitutes a part of the private trade to that country. Though the Chinese are ingenious in the manufacture of a variety of beautiful and permanent colours, they have not yet learnt the art of making Prussian blue.

[60] This valuable article in dyeing was discovered by a Florentine merchant about the year 1300, which not only enriched himself, but was so very advantageous to the Florentines, that they gave him an honourable title, which was borne by all his family and descendants.

[61] When the science of chemistry was little understood, some colours were extremely rare and valuable. Such was the purple of the ancients, which none but the Cæsars were allowed to wear. At the taking of Susa, Alexander the Great found in the royal treasury purple to the value of 50,000 talents, which had lain there 192 years, and still retained its exquisite beauty.

[62] See Fourcroy and Vauquelin on the Germination and Fermentation of Corn and Seeds in *Philosophical Magazine*, vol. xxv. pages 176, &c. and 219, &c.

the proper solvent for each particular resin, and the best temperature for producing the solution.

Within these few years some manufacturers of hats have introduced a considerable improvement into their manufactories, by treating the fur of the hare and rabbit with a solution of mercury in nitrous acid [63]. As this solution of nitrate of mercury is applied before the fur is removed from the skins, it acts on one side of the hairs only, and renders them crooked, which occasions them to felt much easier than they otherwise would.

In the operation of fulling hat-felts, it has been customary to employ a large proportion of wine lees or tartar; and it was imagined that the consistence and density which this gives to the felt, was attributable to the alkali of the tartar; and indeed the author of the French Encyclopédie has affirmed that this is the case. But Mons. Chaussier knowing that cream of tartar is a super-tartrate of potash, suspected that it might be the extra tartarous *acid* which determined the felting; and by direct experiment he discovered this to be the fact, and that any other acid would produce the same effect. Of late years, therefore, those manufacturers who are aware of this circumstance derive considerable advantage from the substitution of diluted sulphuric acid [64].

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[63] See Monge's *Annales de Chimie*, tome vi. p. 300. I have good reason, however, to believe, that this preparation of mercury was in general use by the hatters of America for some considerable time before it was employed in Europe for that purpose.

[64] See *Journal Polytechnique*, cahier i. p. 160; or Nicholson's *Journal*, 4to. vol. i. p. 399.

The consumption of cobalt blue by the blue potters and manufacturers of porcelain, is very considerable; and until lately it was made only from zaffre imported from Saxony, although it has long been known that cobalt ores were to be found in some of the English mines. Just now, however, a few enterprising men have accomplished their reduction, and a beautiful colour, worth from two to three guineas per pound, and much better than what is usually made from zaffre, has been produced in considerable quantities.

Some other cases of equal importance might also be mentioned, but I flatter myself that the examples already adduced are sufficient to show that chemistry is now a necessary branch of the education of youth. Even the management of a GARDEN [65] may receive improvement from a cultivation of this science, as it explains the growth of vegetables, shows the use of the different manures, and directs the proper application of them [66].

The various operations of Nature [67], and the

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[65] An Essay of mine on the advantages of employing common salt in horticulture, and which obtained the annual gold medal of the Horticultural Society of Scotland for the year 1819, may be seen in the 3d volume of the *Memoirs* of that Society; or in the *Journal of the Royal Institution of Great Britain*, vol. x. p. 52.

[66] Natural history in all its branches is intimately connected with chemistry, as it must depend upon this science for any elucidation of the minute properties of those substances, the outward characters of which it describes.

[67] It was a favourite saying of Lord Bacon's, that "man should observe all the workmanship and the particular workings of Nature, and meditate which of these may be transferred to

changes which take place in the several substances around us, are so much better understood by an attention to the laws of chemistry, that in every walk of life the chemist has a manifest advantage over his illiterate neighbour. And it may be remarked, that in case of failure or disappointment in any particular line of commercial manufacture, the scientific chemist has resources as various as the productions of the country in which he lives, to which the uneducated man has no access [68].

Were parents aware of this truth, that sordid maxim *primò vivere, deindè philosophari*, would not be heard; but every youth would be instructed in the first principles of natural philosophy [69] and chemistry, as *the means* of qualifying him for conducting with advantage the concerns with which he might be intrusted. If "knowledge is power,"

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the arts." Lord Bacon's *Advancement of Learning*, book v. 148.

[68] A very remarkable instance of a whole nation availing themselves of advantages presented to them by chemistry, in a case of the greatest emergency, may be seen in *The Chemical Catechism*, Additional Notes, No. 22, p. 426.

[69] Thales the Milesian, who flourished 600 years before Christ, used to declare that he preferred the study of Natural Philosophy to all other sciences.

Democritus of Thrace, who was contemporary with Socrates, applied himself with so much earnestness to his studies, that he was actually absorbed in philosophy, and declared he would prefer the discovery of ONE CAUSE in the works of Nature, to the possession of the whole Persian monarchy.

Paracelsus not only visited learned and scientific men, but frequented the workshops of mechanics, descended into mines, and thought no place mean or hazardous, if it afforded him an opportunity of increasing his knowledge of Nature. Chalmers's *Biographical Dictionary*, vol. xxiv. p. 85.

surely the *love* of knowledge, and a taste for accurate investigation, are the most likely means of conducting to opulence, respectability, and rational enjoyment.

"If," said a late eminent writer, "we would lay a good foundation for a philosophical taste, and philosophical pursuits, persons should be accustomed to the sight of experiments, and processes, in early life. They should, more especially, be *early* initiated in the theory and practice of investigation, by which means, in a great variety of articles, very young persons may be induced to engage with peculiar alacrity in pursuits truly original[70]."

Boerhaave, who had a botanical garden of eight acres, and who was so intent upon stocking it with every exotic that he could procure, as once to have styled a present of a few American seeds, "munera auro cariora," gifts more precious than gold,—was notwithstanding so captivated with chemistry, that he sometimes spent whole days and nights successively in the study and processes of the art.

The history of the progress of science affords, however, few instances of the advantages of philosophical pursuits, greater than the one which modern times have furnished in the invention of the Miner's Safety Lamp. During his inquiries respecting the nature of flame, Sir Humphry Davy discovered that gaseous matter can only be made to burn

[70] Preface to Dr. Priestley's *Observations on Air*, vol. iv. London, 1779.

by its being kept at a high temperature, and that its temperature is lowered in a remarkable manner by making it pass through fine wire gauze. Reflecting on this singular fact, it occurred to him, that some advantage might be taken of the circumstance to prevent the explosions in coal-mines; and this led to the construction of that instrument which has already been the means of saving the lives of some hundred individuals, and which will probably prove a protection to thousands yet unborn. How poor and insignificant are all the honours which rank and power can bestow, when compared to the delightful satisfaction which this great man must derive from the consciousness of having conferred such benefits!

To conclude:——It may be remarked, that it is the necessary consequence of an attention to the science of chemistry, that it gives the habit of *investigation*, and lays the foundation of an ardent and inquiring mind. If a youth has been taught to receive nothing as true, but what is the result of *experiment*, he will be in little danger of ever being led away by the insidious arts of sophistry, or of having his mind bewildered by fanaticism or superstition. The knowledge of *facts* is what he has been taught to esteem; and no reasoning, however specious, will ever induce him to receive as true what appears incongruous, or cannot be recommended by demonstration or analogy.

ESSAY II.

ON

TEMPERATURE.

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PART I.

OF NATURAL TEMPERATURE.

AFTER having given some account of the Utility of Chemistry to the arts, it occurred to me that there would be a peculiar propriety in introducing the following Essays to the notice of the reader, by some remarks on Temperature—as there is scarcely an operation in chemistry, or a process in any of our manufactories, that does not either require a marked attention to the precise degree of heat under which it is conducted, or that would not produce a better result, were this first to be determined by experiment, and made one of the preliminary conditions of the operation.

Besides, if we contemplate the works of Nature, it will be difficult to name any substance that, in the economy of the world, is of equal importance with the matter of heat. What this matter is, or how it produces the astonishing effects which are

attributed to it, we know not; nor have philosophers as yet agreed whether it be really a material ponderable substance, or only the consequence of a particular motion excited among the particles of bodies.

Very delicate experiments have been made, which show that bodies when heated do not increase in weight; but these cannot be considered as decisive, on account of the imperfection of our instruments. A cubical inch of inflammable air requires a good balance to ascertain that it has any sensible weight, and a substance bearing the same relation to this, that this bears to platinum, could not perhaps be weighed by any methods in our possession[1].

So important was this subject considered to be by the late Count Rumford, that in the year 1796 he presented to the Royal Society of London, one thousand pounds three per cent. consols to institute a prize medal to be given once in every two years to the author of the most important discovery on heat, or on light[2].

The word TEMPERATURE is usually employed to denote the precise state of any region on the face of the earth, with respect to heat and cold; or the condition of any particular insulated body, produced by the operation of caloric[3], or by the partial removal of this wonderful and occult power.

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[1] Davy's *Chem. Elements*, part i. vol. i. page 96.

[2] See *Phil. Trans.* for 1797.

[3] This term (caloric) was introduced not from caprice, but

In order to furnish a complete Essay on Temperature, it would be necessary to give a history of all the discoveries which have been successively made respecting the matter of heat, and to detail the various experiments which have been performed by the principal philosophers of Europe for the last two hundred years[4]. This, however, would be incompatible with the design of these Essays, and very uninteresting to the class of readers for whom they are more particularly intended.

But, if I can give such a concise and popular view of the general causes of the change of temperature in bodies, as shall enable the most unscientific reader to understand the subject, and shall, at the same time, teach him how to avail himself of the best means of applying his knowledge in the common concerns of life, I shall be abundantly satisfied[5]. To this end it may be most convenient to divide the subject into two branches, and to treat

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for the sake of giving precision to chemical language, and for the purpose of distinguishing between this peculiar matter itself, and the effects which are produced by it.

[4] That excellent prince, Charles Theodore, Elector Palatine of the Rhine, not only erected an academy which was solely dedicated to these purposes, but he sent collections of the best instruments subservient thereto, and fabricated at his own expense, to all the academies and universities of Europe that were willing to employ them. See Kirwan's Preface to his *Treatise on Climate*.

[5] My idea has beer exactly expressed by our immortal poet:

"For not to know at large of things remote
From use, obscure and subtile, but to know
That which before us lies in daily life,
Is the prime wisdom." MILTON.

it under the distinct heads of Natural and Artificial Temperature.

The variety of climate in the different regions of the earth, the effects of caloric on animal and vegetable life, and the nature of its agency on combustible substances, will arrange themselves under the first division of the subject; while that on Artificial Temperature will contain a brief detail of a variety of expedients for procuring fire, for modifying the effects of heat and cold, for economizing fuel, and for improving certain operations which have a considerable influence on the success of many of the manufactories of the country.

In regard to CLIMATE, it is not necessary to enter into the disquisition, whether the matter of heat be transmitted to us from an immense globe of fire which we call the sun[6]; or whether it may not be more probable that the necessary quantity of caloric for the wants of the world and its inhabitants, was made inherent in the earth[7] at the time of its formation, and that this sun is an inhabited world, with a phosphorescent atmosphere that perpetually sends forth rays of light, and that these elicit, and, as it were, put in motion the matter of heat belonging to this as well as to the other

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[6] See Boerhaave's *Lectures*, Dallow's edit. 4to. vol. i. page 150.

[7] "As the earth is the chief source of heat in the atmosphere that surrounds it, distance from the earth is a source of cold. Hence, the highest mountains, even under the equator, are, during the whole year, covered with snow." Kirwan *On Climate*, 8vo. 1787, pages 6 and 7.

planets—I say, it is not necessary to adduce arguments in favour of either the one or the other opinion; for this would open too wide a field of discussion, and would be very unsuitable to that brevity which I am anxious to observe, and to that general UTILITY which I have placed before me as the main object to which I aspire.

I am desirous, however, of making a few desultory observations on this point, before I proceed. And in the first place it may be remarked, that the sun's rays appear to have no power of giving heat unless they impinge against a solid body. The focus of the most powerful burning glass, if directed on mere air, does not produce the smallest degree of heat. Thus Mons. Charles, the aëronaut, found the air in the neighbourhood of Paris to be 47°; and when he had ascended to the height of eleven thousand feet, only 21°, or 11° below the freezing point.

The theory of the sun not being the source of caloric enables us to solve the great difficulty concerning the distribution of heat among the different planetary bodies; for, according to this view, those nearest the sun may have no more than those at the most remote distance. We have only to suppose the quantity of caloric to be proportioned to the distance; and if a *small* quantity exists in the planet Mercury, no more heat may be excited than is done by a *larger* quantity in Saturn [8].

[8] See Millar's *Physical and Metaphysical Inquiries*, London, 1806.

Moreover it is evident that there must be other causes besides the sun's rays, which operate in the production of variety of climate; for the hottest days are frequently felt in the coldest climates, and the coldest weather and even perpetual snow are found in countries bordering on, or even immediately under the equator.

That we are indebted to the sun for some of the most beneficial effects of caloric, cannot however for a moment be disputed: nor will it be denied that the difference of climate on the various divisions of the earth, is, in a great measure, occasioned by the relative situation of the different regions with respect to that luminary; and that the Author of Nature had an eye to the general felicity, in the curious adaptation of the animal and vegetable creation (in their primitive constitutional qualities and texture of parts) to this great variety of situation and climate.

How strange then must that hypothesis of Mons. Buffon appear, which supposes that the earth and all the other planets were once in a state of fusion[9]; that they are now gradually cooling; and that a

[9] To some such conceit as this, the following lines probably owe their origin:

"When high in ether with explosion dire,
From the deep craters of his realms of fire,
The whirling sun this ponderous planet hurl'd,
And gave the astonish'd void another world:
When from its vaporous air condens'd by cold,
Descending torrents into oceans roll'd;
And fierce attraction with relentless force
Bent the reluctant wanderer to its course."

time will come when they will have lost so much of their present heat as to be totally unfit to preserve either animal or vegetable existence! As if the Great Architect of this stupendous world had neglected to provide against its degenerating into an useless mass of inert matter.

Fortunately, however, we are not obliged, even on the authority of so great a name, to believe this monstrous and incongruous representation. For all history abounds with circumstantial details, which directly contradict the assertion, and tend, on the contrary, to prove that some of the cold regions of the earth have become much warmer than they were eighteen hundred or two thousand years ago [10].

The following are a very few of the many instances which might be adduced:

In the Augustan age, the Rhine and the Danube were commonly frozen over during several months of the year; and when the Barbarians overran the Roman empire, they transported immense weights and innumerable armies across the ice of these rivers [11]; a thing which in the present times would be impossible. The rein-deer and the elk, which flourish only in the coldest climates, the former be-

[10] So early as in the beginning of the last century, Mons. de Mairan gave it as his opinion that the earth is more indebted to the matter of heat inherent within itself than to the sun for the degree of temperature which it experiences; and after a lapse of forty-nine years this eminent man embodied his ideas, and published his reasonings on the subject in an elaborate Memoir, which may be seen in the *History of the Royal Academy of Sciences at Paris, for the year* 1766.

[11] Diodorus Siculus, lib. v. page 340, edit. Wessel.

ing found, not only in the wilds of Siberia, but on the rocks of Spitzberg within ten degrees of the pole, were in the time of the Cæsars abundant in the Hercynian forest, which was said to be sixty days journey in length, and which covered a great part of that vast country lying between Switzerland and the Black Sea [12]. All the rivers throughout this region were perpetually bound up with ice during the whole winter, which usually lasted for eight months [13], and the cold was so excessive that the historians of the time evidently supposed that the countries north of this district must be absolutely uninhabitable. Ovid says that at Tomi, which was seven degrees south of London, the snow continued two years on the ground; and Virgil agrees with him in declaring that the people living on the banks of the Danube were accustomed to cut out their wine with hatchets [14], and to deliver it to their guests in solid portions [15]. These, and various other instances, incontrovertibly prove that Europe, at least, was formerly much colder than it is at present.

The same change has also taken place on the

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[12] Cæsar *de Bel. Gal.* vi. 23, &c.

[13] Herodotus, lib. iv. § 28.

[14] Ovid. lib. iii.; Xenophon. *Anabasis*, lib. vii. p. 560, edit. Hutchinson.

[15] "But where Mæotis Scythia's waste divides,
And turbid Ister rolls his yellow tides,
There stalls inclose the herds that never stray,
No grass the field, no leaves the wood array;—
There crystal chains at once whole pools confine,
And hatchets cleave the congelated wine."
Sotheby's *Georgics of Virgil*, book iii.

continent of America. Formerly the people of Guiana, within five degrees of the equator, could not live without lighting evening fires; and though it is not a century since a part of this country was cleared from wood, the heat in that part is already excessive[16]. The parts of North America which have been cleared are also much warmer than they were when the woods were standing.

It has sometimes been imagined that difference in climate is occasioned *solely* by the relative situation of the different countries with respect to the sun; but nothing can be more erroneous, as appears from the state of the Andes which may be adduced as a complete refutation of this idea; for between the base and the summit of these mountains every degree of temperature may be found. The city of Quito, situated about the middle of one of these, experiences a mild and temperate climate, while the sands beneath it are intensely hot, and the ground above it covered with perpetual snow.

There are so many facts which tend to prove that the climate of a country is not occasioned solely by its situation on the face of the globe, that I am inclined to think many an inhospitable clime might be rendered healthy and uniformly temperate, by the resolute exertions of a good government and an enlightened population.

The country on the borders of the Albany River, and the southern parts of Labradore, are in the

[16] Supplement to Buffon's *Natural History*, 8vo. page 346.

same latitude with Great Britain [17]; and yet the cold is now so severe, and the snow so perpetually on the ground, that the lands lie entirely uncultivated. The climate of Newfoundland, which is situated still further south than this island, is more like that of the north of Russia than England; and those who have travelled in Canada, which lies in the same parallel of latitude with the finest vineyards of France, assure us that the great river St. Laurence is frozen over for many months, while the correspondent provinces in Europe experience the most genial temperature.

Dr. Robertson, indeed, supposes [18] that the difference of temperature between certain parts of Europe and similar latitudes in America is equal to twelve degrees, and that a place thirty degrees from the equator in the latter, is as warm as one situated at eighteen degrees from it in the former.

There is also nearly as much variation in the climate of some countries situated near the line. Thus, many parts of Peru are mild and temperate, while the correspondent latitudes on the continent of Africa are scorched by the burning heats of the torrid zone [19].

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[17] According to the observations made at the house of the Royal Society from the year 1772 to 1780, it appears that the mean annual temperature of London is 52°. The greatest usual cold is 20°, and happens in January; and the utmost degree of heat is generally 81°, which commonly happens in July.

[18] *Hist. of America*, vol. ii. page 472.

[19] On the road from Senegal to Podor the heat is frequently 111°. At Pondicherry it has been 113° and 115°. Kirwan *On Climate*, pages 99 and 101.

A person accustomed to the examination of the works of Nature, can scarcely avoid being often very much impressed with the consideration of the beauty and excellence of the arrangements which its divine Author has established, for the preservation of the world and the various animated beings which inhabit it. Some of these native and original appointments are contrivances of great wisdom. Of this class, the following appears to me to be a most striking instance, though not often adverted to.

Land is capable of receiving much more either of heat or cold, than water. Saussure, when the air was at 81°, found the Lake of Geneva at the surface was 62°, and at the depth of eighty-seven feet only 55°. In the neighbourhood of Marseilles, Dr. Raymond often observed the land heated to 160°; but the sea was never hotter than 77°, and even this heat it received chiefly by its communication with land; for in July 1765 he found that the part of the bay next to the land was at 74°, the middle of the bay 72°, and the entrance of the bay only 70°. On the contrary, he frequently observed the earth in winter cooled down to 14° or 15°; but the sea was never lower than 44° or 45° [20].

That the land has an effect on the waters of the vicinity, also lowering its temperature, appears from the fact that some of the inland seas of Europe, even of great extent, have sometimes been entirely frozen

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[20] *Mém. de la Société de Med. de Paris*, An 1778, page 70. Kirwan *On Climate*, page 34.

over. In 1668 the Baltic was so firmly frozen that Charles the XIth of Sweden and his whole army passed over it[21].

Were it otherwise, and that the waters on the face of the earth had the property of acquiring the same temperature either of heat or cold as the land, the evaporation in summer would be excessive and detrimental; and in winter all navigation would be suspended, and the finny inhabitants of the water would inevitably perish.

Having adverted to this subject, it would be improper to allow it to pass without noticing one or two of the causes which constantly act to modify the temperature of the seas and other large bodies of water. In hot climates, the seas, rivers, and lakes, are prevented from acquiring any thing like the heat of the adjacent lands, by the evaporation which is continually going on at the surface, and which carries off the greater part of the heat as fast as it is received. This principle of evaporation producing cold, has been long understood, and will be explained as we proceed.

On the contrary, in winter, whenever the temperature of the atmosphere is so far reduced as to give the waters a tendency towards freezing, those

[21] *Puffend. Hist. Europe. Mod. Univ. Hist.* in 8vo. vol. xxx, page 180. In 1709 the Adriatic was completely frozen over. *Mém. Par.* 1749.

[22] A patriotic writer, when mentioning this and other of our British lakes, recommends it to Government to have them all well stored with the spawn of the various sorts of fish that will not live in rivers; and that this may be done for the support of

particles of water on the surface which are first cooled, acquire a greater specific gravity, and sinking within the mass, warmer particles of water ascend to supply their place, which are cooled in their turn, and descend also. Thus a circulation between the surface and the lowest depths of the sea and of other large bodies of water is constantly kept up, which often tends, among other important purposes, to preserve them from congealing for a long period after the air is reduced to the freezing point.

As the operation of this principle is uniform, it might be expected that the deepest lakes would remain the longest unfrozen; and this is really found to be the case. Near Lochness in Scotland there is a small fresh-water lake on the top of a very high mountain, the water of which never freezes; and near Mohanagh, the seat of Roger Fenwick, Esq., in the county of Cork, there are two small lakes, very deep, that produce trout of an unusual size [22], and never freeze during the most severe winters, owing to the time between the end of one summer and the beginning of another not being long enough to allow of this circulation being completed [23].

It might however be supposed that whenever this circulation ceases from the increase of the cold, the

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the poor in their respective neighbourhoods. Campbell's *Political Survey*, vol. i. page 106. The pedlars of China, it is well known, carry jars of spawn about from one province to another through the whole empire, for this very purpose of stocking the lakes with all the different kinds of lake-fish.

[23] *Ancient and Present State of the County of Cork*, book ii. chap. iv. page 264.

density of the freezing water would continue to increase also, and that the ice, as fast as it is formed, would be precipitated. But here, Nature, all bountiful, has made a memorable deviation from her usual course; for no sooner is the water cooled down to 40—5°, than it not only ceases to increase in density, but, on the contrary, actually becomes of less and less specific gravity, as the caloric is further abstracted by the cold atmosphere.

When this diminution of specific gravity has begun to take place, the water continues enlarging its bulk in regular gradation, until the surface becomes cooled down to 32°, when, if the water be still, a film of ice forms and covers the whole mass. If the cold continues, this covering of ice increases in thickness, and attaches itself firmly to the banks, so as entirely to cut off all communication with the atmosphere, and thus prevent that abstraction of caloric which otherwise would soon convert the whole mass of water into ice.

No person, who has paid even a slight attention to chemical science, can be ignorant of one of its principal axioms, that solids and fluids acquire density by the loss of caloric; it is therefore surely worth while to inquire why this general law of nature has been departed from in this instance, and to consider, what would have been the result had water been subjected to the same law with other bodies?

It has before been remarked, that as water loses caloric it becomes more and more dense until it is cooled down to about 40°; but if no check had been given

to this process, and the density of water had continued to increase until it came down to 32°, the superficial stratum would have continued to descend, followed by others in quick succession, and a body of ice would have first formed at the *bottom* instead of at the *surface* of our lakes and rivers. This would have accumulated with such rapidity, that one severe winter would, in all probability, have converted the whole of most of the rivers of Europe into as many solid masses of ice; which, on account of their great thickness, no future summer would have been able to dissolve.

It is certainly extremely curious that the same cause should thus be made to produce effects which, apparently, are diametrically opposite:—That water, within a certain range of temperature, should have its specific gravity *increased* by the loss of its caloric; and then, on a sudden, that the action should be reversed, and its specific gravity *lessened* by the same operation.

It will now be perceived, that this curious contrivance was absolutely necessary for the preservation of the world; and it is pleasing to consider how many inconveniences are avoided by this very simple deviation from the usual course of Nature. The sheet of ice which often covers the small seas, as well as the rivers and the lakes, not only preserves a vast body of caloric in the subjacent water, but when it thaws, the fish are not destroyed by the cold; for not a particle of the cold surface-water

can descend, until a change in the temperature of the atmosphere has taken place, so as to raise the temperature of the whole of the water at least ten degrees.

The next branch of our subject embraces the *effects* which are produced on animal and vegetable life by change of temperature; but as these are too various to be even barely enumerated within the compass of an Essay, the mention of a few of the most interesting must suffice.

The first idea which naturally presents itself on this subject is, that nothing but consummate wisdom could have suggested the formation of such an infinitude of animals and vegetables[24] of various natures and properties, and all peculiarly adapted to the various climates in which they are respectively placed:

> Life buds or breathes from Indus to the Poles,
> And the vast surface kindles as it rolls!

It is not, however, a little remarkable, that while every climate on the face of the earth, and almost

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[24] Dr. Kirwan has remarked that "every habitable latitude enjoys at least for two months a heat of sixty degrees; which heat seems necessary for the growth and maturity of corn." *On the Temperature of different Latitudes*, page 105.

[25] Messrs. Humboldt and Bonpland, in travelling through the province of Quito in South America, perceived live fish thrown up from the bottom of a volcano, in the course of its explosions, and they appeared to be in perfect health, although the water

every situation [25], has a race of animals peculiarly fitted for it, and that can flourish and propagate no where so well as in their native quarter of the world, and in their own appointed localities, man should be so organized that he can reside, increase and multiply on every part of the habitable globe.

It is also observable, that while the cold-blooded animals vary their animal temperature with every alteration of the medium in which they live [26], the mechanism of the human body is such, that it is capable of preserving nearly an equable temperament, whatever may be its situation, or however great the transition from its accustomed state, to the highest degree of heat that it can endure, or to the most intense cold; that is, the temperature of the human body is always the same, or nearly so, in all climates.

Of this singular faculty no satisfactory elucidation was afforded until Dr. Crawford, in 1779, published his Experiments and Observations on Animal Heat. This eminent philosopher explained it on the well known chemical principle of different substances having different capacities for caloric; on the property that the matter of heat has of becoming

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and heated vapour that came up with them, raised the thermometer to 210°; which is only two degrees short of the boiling point. *Recueil d'Observations de Zoologie et d'Anatomie comparée.*

[26] To establish the truth of this, many facts might be adduced. Frogs have been frozen so hard, as to chip like a piece of ice, and yet by a careful and gradual increase of temperature have been reanimated. On the contrary, worms of the species of Tænia have been taken alive out of the body of a boiled carp.

latent; and on the fact, which he discovered, that arterial blood has a greater capacity for the matter of heat than venous blood. But that this may be more clearly comprehended by all classes of readers, it may perhaps be necessary to proceed a little further into this part of our subject.

It was formerly presumed that caloric, in whatever state it might be, could always be measured by the thermometer [27]. But the important experiments of Dr. Black and others have shown, that besides the caloric which acts upon, and is appreciable by, the thermometer, there are other portions which are in such close union with most bodies, as to occasion no sensible variation in their temperature. That is, caloric may be so combined with a body, as to have lost all power of affecting the most delicate instrument; yet, when this latent heat is set at liberty, and converted to free caloric, as it is called, this shall be as active, and as energetic, as though it had never been confined [28]. A single example will be sufficient to adduce, by the repetition of which any one may satisfy himself of the truth and propriety of this distinction.

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[27] There are four different thermometers employed in Europe. This often occasions much inconvenience. Ours has the scale of Fahrenheit, the zero of which commences at 32° below the point at which water freezes; and between this and the point at which water boils, it is divided into 212 degrees. The late Dr. Kirwan proposed that the use of all these thermometers should be discontinued, and a general one constructed, beginning at the congelation of mercury, and terminating at the ebullition of water, and to be divided into 250 degrees. The late Dr. Murray of Edinburgh suggested that it would be convenient to form

Put about half an ounce of cold water into a small phial, and add to it, *very gradually*, about an equal measure of oil of vitriol, gently shaking the phial after every addition of the acid. The consequence of this will be, that the water will immediately begin to give out its latent caloric; and when so much oil of vitriol has been added as is equal to double the measure of the water, the mixture will assume a degree of heat superior to that of boiling water.

In regard to the operation of this principle in the act of respiration, Dr. Crawford thus explained it: The oxygen, said he, which is one of the component parts of atmospheric air, has a large portion of caloric chemically combined with it, and a great part of this caloric is taken up by the blood, every time that the atmospheric air passes through the lungs [29]; the internal surface of which, according to anatomists, is equal to the external superficies of the whole body; and on this *extended* surface it is that the arterial blood, through the medium of a thin pellicle, is exposed to the influence of the respired air.

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a scale whose extreme points should be the temperatures of freezing and boiling quicksilver, and to divide this scale into 1000 degrees. Kirwan *On the Temperature of different Latitudes*, 8vo, 1787, preface, page vii. Murray's *Chemistry*, 8vo, 1809, vol. i. page 139.

[29] A luminous explanation of the doctrine of latent heat may be seen in Dr. Robison's preface to Dr. Black's *Lectures*, 4to, p. 34, &c.

[30] Every time we make an inspiration, the bone of the breast rises and the diaphragm sinks. By these two contrivances room is made for a pint and a half, or more, of atmospheric air, at every drawing in of the breath.

How then is it that the lungs are not injured by this great accession of the matter of heat? This is a difficulty which Dr. Crawford has explained by the discovery, that arterial blood has the property of arresting this caloric, and of chemically combining with it—that is, of absorbing it in the same way as ice at 32° absorbs caloric, without becoming warmer, in the least degree, by the addition: and that when this blood flows from the arteries to the veins, the case is altered, and, by some unknown contrivance, its capacity for caloric is then lessened, and what was latent or combined caloric in the arteries, becomes free [30] caloric, or sensible heat in the veins [31]; and as these branch out in infinite ramifications to every extremity of the body, the genial warmth is conveyed through these channels to every part. And when the blood returns to the lungs [32], its former capacity is restored, and it again loads itself from the atmospheric stores, and distributes the caloric, as before, to every even the most minute vessel in the animal system.

When this theory was first published, it was naturally asked, What becomes of the azote, which is

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[30] An example of a contrary effect may be found in the conversion of ice into water. Let one pound of ice at 32° be dissolved in one pound of water heated to 172°, and it will be found that 140 degrees of heat have disappeared, and become latent in the fluid, which assumes a temperature of 32° only; whereas, if a pound of water at 172° be mixed with a pound of ice-cold water at 32°, the temperature of the mixture will be exactly 102°, which is the mean of 32° and 172°. Ice requires 140 degrees of caloric to give it fluidity, and this it receives without the least augmentation of temperature.

also a component part of atmospheric air? and whether a great portion of the caloric would not be required to preserve this azote in the state of gas, so that it might be expelled from the lungs when the oxygen was separated from it? And that as a part of this oxygen takes up carbon from the blood, whether the remainder of the inhaled caloric would not be necessary for the formation of carbonic acid gas, which, it is well known, is also thrown off in the act of respiration [33]?

But here another remarkable contrivance presents itself, and it is one that is equally necessary to the uniform preservation of animal heat. This I cannot explain with more conciseness, than by transcribing the following note from the Chemical Catechism.

"It is not simple azote or nitrogen, which is thrown out of the lungs in respiration, but *nitrogen gas*; and it has been imagined that, when atmospheric air is decomposed by the lungs, part of the disengaged caloric is required for the nitrogen, to preserve it in the form of gas: but it is a very curious fact, that nitrogen gas and carbonic acid gas

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[31] If the reader have an opportunity of referring to the third chapter of the *Chemical Catechism*, tenth edition, pages 59—64, he will find several instances adduced, whereby the difference between latent and free caloric is explained.

[32] The blood of the veins is black, or purple; but as it passes through the lungs it deposits charcoal, and becomes, when it enters the arteries, a bright scarlet.

[33] Lavoisier discovered that atmospheric air abstracted carbon from animal blood. His first paper on respiration was read to the Academy of Sciences on the 3d of May, 1777, and is printed in their volume for the year 1780.

have less capacity for caloric than any other gaseous substance. It is a general characteristic of the gases, that they absorb a large portion of caloric to preserve them in a gaseous form. Yet one of these gases has less capacity for caloric than many liquids, and the other (nitrogen gas) less capacity than even ice[34]."

When this beautiful theory for the explanation of the production of animal heat was first proposed, most of the philosophers of Europe acquiesced in it, and it continued to be generally received for many years after the death of its learned and ingenious author. Some considerable physiologists have, however, of late years offered several objections to Dr. Crawford's reasoning, especially Mr. Brodie, whose paper was published in the Philosophical Transactions for 1812; but none of these writers have as yet favoured the world with a theory that is less objectionable, or that will explain the phenomena attendant on respiration and on the evolution of animal heat, in a more satisfactory manner.

We shall, however, at all events, be justified in saying, that the arrangements, whatever they may

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[34] *Chemical Catechism*, tenth edition, chap. ii. page 52.

[35] "A thermometer with its bulb under the tongue, or buried in a wound in any fleshy part of the body, always indicates a heat of 97° or 98°, be the temperature of the air what it may." Dr. Skrimshire's *Essays*.

[36] A paper by Dr. Blagden on the Congelation of Mercury in these parts, may be seen in *Philosophical Transactions*, 1783.

[37] Some idea of the very low temperature of frozen mercury may be derived from the circumstance, that if a lump of it be

be, for the production of animal heat, and for the preservation of life, are equally operative in every climate and in every situation in which man is likely to be placed: for, not to advert to other causes, it may be remarked, that in climes intensely cold the atmospheric air is more condensed, and consequently more caloric is taken in at every inspiration [35].

In many of the habitable parts of the Russian empire the cold is often sufficiently intense to freeze mercury [36]; although, as is well known, that fluid metal does not become a solid until it be reduced to the temperature of 71 degrees below the point at which water freezes [37]: and it is observable, that when men have been accustomed to cold climates, so as to know the precautions [38] necessary to be taken, they can endure more severe cold than even this, without sustaining any permanent injury.

Many of the natives of Great Britain make annual voyages to Greenland, and stay there during the fishing season, where the cold is greater than most people can imagine. Some idea of it may, however, be formed from the account we have of the masses of ice which are generated there, and float

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dropped into a small quantity of water at the boiling point, it will abstract the caloric with such rapidity that the mercury will instantly become fluid, and the hot water will at the same moment be converted into ice.

[38] One precaution necessary to be observed in such situations, is, not to handle any metallic body; for, if an instrument or utensil of iron, or any other metal, which had been exposed to the cold atmosphere, were touched, a sensation would be felt like that of burning, and the part would, in all probability, be blistered.

occasionally from thence into the Atlantic Ocean. "These mountains of ice," says Dr. Troil, "which are often seen fifty feet or more *above* water, are at least nine times[39] the same depth *below* water[40]. Frequently these immense masses are left in shoal water, fixed, as it were, to the ground, and in that state remain many months, nay years, undissolved[41], chilling the whole of the atmosphere for many miles round[42]."

The Stockholm Memoirs for 1757 mention a fact which fully corroborates this statement of the effect of mountains of ice or snow on the atmosphere. "When," says the writer of that paper, "a north-west wind blows on the mountains of Norway, it occasions a thaw; but when it has passed these mountains and entered Sweden, it produces the most intense cold."

Moreover, Mr. MacNab, when in Hudson's Bay, experienced a cold so intense as to sink the spirit thermometer to 82° below the freezing point, which, if his instrument did not deceive him, was eleven degrees below what is required for freezing mercury[43].

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[39] Mr. Boyle found by experiment, that a cylinder of ice floating in water of the same specific gravity as that of which it was made, could rise only one tenth of its height above the surface of the water. Boyle's Appendix to *The History of Cold*, p. 16.

[40] The account which Pennant in his Arctic Zoology has given of the ice mountains at Spitzbergen is grand and interesting. The "collision," says he, "of the great fields of ice, in high latitudes, is often attended with a noise that, for a time, takes away the sense of hearing any thing else; and the lesser, with a grinding of unspeakable horror."

On the other hand, whenever an animal is placed in a medium the temperature of which is considerably high, the usual change of arterial into venous blood does not take place; consequently there will be no evolution of caloric, and the animal heat will not rise much above the natural standard: but the problem has not yet been solved, how high is the degree of heat which the human frame can endure without injury.

Sir Joseph Banks and Sir Charles Blagden once attempted to ascertain this, and for some time actually breathed an atmosphere, in a room prepared by Dr. Fordyce, which was fifty-two degrees higher than that of boiling water [44].

Other instances equally extraordinary are related by Mr. John Mason Good, (now Dr. Good,) in an anniversary oration which that gentleman delivered before the Medical Society of London, on the 8th March 1808.

During the time that Sir Joseph Banks and Sir Charles Blagden submitted themselves to Dr. Fordyce's experiment, the temperature of their bodies was not at all raised; though their watch-chains,

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[41] The extreme hardness of these masses of ice is owing perhaps to their having been formed with salt water. There is a memoir on this particular question in the 15th volume of *The Philosophical Transactions*, No. 167.

[42] Crantz's *Hist. of Greenland*. Forster's *Voyage* in 1773, p. 69. Troil's *Iceland*, Lond. 1780, 8vo, page 49.

[43] *Philosophical Transactions*, vol. lxxvi. page 271.

[44] The oven-girls in Germany often sustain a heat of from 250° to 280°, and one of these girls once breathed in air heated to 325° of Fahrenheit for the space of five minutes. *Hist. Acad. Sciences*, 1764.

and every thing else metallic about their persons, were so heated that they could not bear to touch them[45]. The thermometers which hung in the rooms always sunk several degrees when either of the experimentalists breathed upon them or touched them; and to prove that there was no fallacy in the degree of atmospheric heat shown by the thermometer, "we put," says the reporter, "some eggs and a beef steak upon a tin frame in the room, and in 20 minutes the eggs were taken out roasted quite hard, and the beef steak was overdone in 33 minutes."

Water placed in the same room did not, however, acquire a boiling heat until a small quantity of oil was dropped into it, when it soon began to boil briskly. The evaporation from the surface of the water had prevented it from acquiring the heat of 212°; but when that surface became covered with a film of oil, the evaporation could not go on, and ebullition commenced[46].

That evaporation produces cold, is a very familiar axiom in chemical science: and this principle is operative also in the regulation of animal heat; for, whenever the human body becomes oppressed by heat, if it be in a state of health, perspiration commences, and this carries off the superabundant caloric as fast as it is produced.

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[45] "The heat of metals at the temperature of 120° is scarcely supportable; water scalds at 150°, but air may be heated to 240° without being painful to our organs of sensation." Davy's *Elem. of Chem. Philosophy.*

[46] Sir Charles Blagden's relation of these very interesting experiments may be seen in the *Phil. Trans.* for the year 1775.

These effects of perspiration, which are so extremely beneficial in the animal economy, arise from a well known chemical principle, viz. that water cannot be converted to vapour until it has combined with a very large portion of caloric. Thus, in all oppressive heats, the fluids of the human body are determined to the surface, from whence they escape in the gaseous form, carrying off with them that superabundant heat which otherwise would soon have become insupportable [47].

That perspiration actually does operate in this way, may be readily conceived by those who know that a thermometer plunged into steam indicates only the same degree that it would in boiling water, although the steam contains nearly one thousand degrees more of caloric chemically combined with it, and that, owing to its being in a latent state, it is not appreciable by the thermometer.

It is by this combination with caloric that steam is enabled to preserve its gaseous form, in which state it occupies a bulk 1800 times greater than that of water [48]; and this is the only way in which we can account for the loss of that continued stream of caloric which is perpetually passing, and often

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pages 111 and 484, &c., and a series of experiments by Dr. Crawford, on the power that animals possess of producing cold, will be found in *Phil. Trans.* for 1781, page 479.

[47] Dr. Valangin has written a valuable paper on perspiration: but he has not treated of it very scientifically. Valangin's *Treatise on Diet and the Management of Human Life*, 8vo, London, 1768.

[48] Murray's *System of Chemistry*, vol. i. page 421.

for many hours, through the bottom of an evaporating vessel, or other boiler of water, when placed over an intense fire[49]; because, if the fire be the same, the water actually admits as much caloric after it boils, as it did before, although that which it now receives does not, in the least, augment its temperature.

The temperature of boiling water is usually 212°, and the constant evaporation prevents it from ever acquiring a higher temperature, however intense may be the fire that is placed beneath it. In like manner, the natural temperature of the human body is about 96° or 98°; and whatever may be the degree of heat to which it is exposed, the animal perspiration always carries off the superabundant quantity, and prevents it from ever acquiring a temperature much beyond the usual standard.

These multiplied contrivances for the preservation of life, by maintaining an uniform animal temperament, were surely not the offspring of chance; their peculiar adaptation shows them to be a part of the great scheme of unerring Wisdom, effected by a Being who wills the convenience and felicity of his creatures.

There is still some intricacy respecting the nature of the operation of caloric on combustible sub-

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[49] A more detailed explanation of this may be seen in *The Chemical Catechism*, tenth edition, page 71.

[50] See *Mém. de l'Acad. des Sciences pour l'An.* 1774 et 1775, page 520.

stances; and this will not seem surprising when we consider, that all the theories of combustion which were promulgated before the time of Lavoisier are now deemed extravagant, or at least very unsatisfactory. A short sketch, therefore, of the very ingenious theory which this eminent philosopher published about the year 1775, to explain the phenomena of combustion [50], may perhaps be acceptable to those persons who have had no opportunity of investigating the subject.

"Some bodies (said he) are combustible, others are incombustible. If a body which is formed of combustible materials be heated to a certain degree in atmospheric air, combustion will commence, and its affinity for oxygen will be so great that it will abstract it from the atmosphere. Should the combustible substance be placed in favourable circumstances, with the free access of atmospheric air, this perpetual accession of oxygen will keep up the combustion until the whole of the combustible matter becomes saturated with oxygen, and then, in popular language, it is said to be consumed."

The heat, in this process, generally arises from the decomposition of the oxygen gas of the atmosphere; but he thought it probable that the light [51] and the flame in most cases proceed from the combustible body itself, and that combustion is a mere

[51] For an account of the colours of the light which proceeds from different combustibles, the reader may consult Dr. Fordyce in the *Phil. Trans.* for 1776, and the Rev. W. Morgan in *Phil. Trans.* for 1785.

chemical process, a double decomposition, in which not only two compound bodies are separated into their original elements, but two new compounds are always formed. For while the light, which is extricated from the burning substance, unites with the caloric of the oxygen gas, and produces what is called fire, the oxygen itself combines with the base of the combustible, and forms a new incombustible substance. This incombustible matter will be either water, an acid, or an oxide; or a compound of two or more of these substances.

In this view of the subject, combustion can never take place in vacuo. Atmospheric air, or some other compound containing oxygen, must, as he asserted, be present in every instance of combustion; and this he explained by reference to a variety of direct experiments.

Since the time of Lavoisier, however, several objections have been urged to this theory; most of which have been detailed by Professor Brande in his Manual of Chemistry, vol. i. page 317, and by Dr. Ure in his Dictionary; and these, together with the discovery that chlorine and iodine will support combustion, neither of which contains oxygen, have entirely confuted the French assertion that oxygen, or some of its compounds, must be present in every case of combustion. We are therefore now compelled to come to the conclusion, "That combustion cannot be regarded as dependent upon any peculiar principle or form of matter, but must be considered as a general result of intense chemical action."

It must, notwithstanding, be observed that nothing has occurred to refute the generally received opinion, that in all the ordinary cases of combustion, it is the oxygen of atmospheric air, and that alone, which supports the combustion.

The necessity for the presence of oxygen in the more familiar cases of combustion is so clearly exemplified in a certain operation on cotton goods, not universally known, that I conceive it may be useful to advert to it. The process to which I allude, and which is very common in Lancashire and other calico-printing districts, is called singeing, and has been contrived for the purpose of taking off all the ends of the threads and other downy filaments that are usually attached to the piece, and of giving the whole a smooth surface.

To effect this, several pieces of calico, previously fastened together by their ends, are lapped smoothly round a large wooden roller, from which, by a regular motion, they are passed over a large semicircular piece of cast iron, which, by means of a furnace placed immediately beneath it, is constantly kept at a full red heat.

Calicoes, muslins, dimities, fustians, &c. are treated in this manner, and the subsequent bleaching takes out any stains which they may have contracted from the iron [52].

To a stranger, this may seem a very destructive operation (and no one can witness it for the first

[52] See the Essay on Calico-Printing in these volumes.

time without astonishment); but by the quickness and regularity of the motion, and by the uniform pressure of the cloth upon the hot iron, the combustion that would otherwise take place is prevented, and nothing is burnt but the loose threads that rise above the surface of the fabric. The peculiar effect that is here produced, and how the cloth is protected from the red-hot metal, may be thus explained.

The uniform *pressure* of the cloth upon the heated cylinder, keeps that part of it which is directly over it in close contact, so that there is no space for the intervention of any more atmospheric air than is just sufficient to occasion the combustion of the mere superficial filaments of the cotton or linen; and this is the only effect which the manufacturer is desirous of producing.

This process, which is now universal with the printers of cotton goods, explains why our housewives cannot get up their home-spun linen with so neat a face as that has which is sold in the shops. There are some intelligent laundresses, however, who are fully aware of the principle on which the above-named process is founded; for, when about to iron their clothes, they dismiss all anxiety about the precise degree of heat; as they well know that, however hot their flat-irons may be, if they press them with all their force upon the linen, and that the linen be smoothly spread, it will never sustain any injury.

It has already been remarked, that in the ordinary

cases of combustion which occur in consequence of, and are supported by, the constant presence of oxygen, during the process the oxygen combines with the base of the combustible: but there is another axiom of equal importance to be impressed on the memory of all those who are likely to be engaged in any kind of chemical operations, viz. "That every body increases in weight by the operation of combustion[53]." This may perhaps require a little explanation, but it is a law of Nature to which there is no exception.

Even the incipient combination of oxygen with a body increases its absolute weight, as is well exemplified in the formation of the metallic oxides; the metals always acquiring additional weight by being converted into oxides. Thus, by exposing melted lead to the action of the atmosphere, under a peculiar management, red lead is formed, and a ton of pig lead will yield 22 cwt. of red lead.

But where complete combustion takes place, this increase is generally more considerable: thus, if 100 pounds of zinc are burnt in a proper apparatus, flowers of zinc will be formed, and the product will be 125 pounds. If spermaceti oil be burnt in a way that the product can be examined, it will be found that the whole is converted to carbonic acid and water, and that every hundred ounces of the oil have produced 130 ounces of water. In like man-

[53] I believe Lavoisier was the first chemist who proved this by direct experiment. See *Essays Physical and Chemical*, page 297. This work was published in Paris in the year 1774.

ner, if phosphorus be burnt by a rapid combustion, it will attract oxygen from the atmosphere, and become phosphoric acid, and every pound of the phosphorus thus employed will produce more than two pounds of acid [54].

It would be fruitless to enumerate more instances, though I thought it right to mention a few obvious examples in passing, because I have met with many intelligent people who had never annexed any idea to combustion but that of absolute destruction; and yet I know of no subject connected with the economy of the world, which it is of more importance to investigate, or which is better calculated to give us exalted conceptions of the arrangements of that Being who hath not only formed a perfect whole, and pronounced every part to be in itself good, but has so constituted things that none of the materials which he has employed in the construction of the world can ever be lost or destroyed [55].

Metals, by means of oxygen, may be converted to pulverulent and even impalpable substances; but, whenever the oxygen is abstracted, every character of the original metal will be restored. All sorts of combustible substances may be employed for the

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[54] It has been remarked, page 79, that we are indebted to Lavoisier for the true theory of combustion; but the full development of the theory was not published until the year 1777. See *Mémoires de l'Acad.* for that year, page 592. It was afterwards further explained in the volume for 1783, page 505.

[55] See a further elucidation of this subject under the title of "The indestructibility of matter," in the *Chemical Catechism*, Additional Notes, N° 25 & 26, tenth edition, pages 430, 431.

necessary purposes of increasing temperature: the caprice of man may commit many invaluable, as well as worthless substances, to the flames; or the lightning of the heavens may involve a whole district in one general conflagration, in which every thing combustible shall be reduced to ashes:—but let it be remembered, that the act of combustion only separates the particles of bodies, and puts them in a state to form a variety of new combinations equally useful and necessary in the order of the Universe.

And shall we be told that such a state of things is the effect of chance? Certainly not. An eminent philosopher of the present day[56] has well remarked, in opposition to such absurdity, that "in the Universe nothing can be automatic, as nothing can be said to be without design. An imperfect parallel," says he, "may be found in human inventions. Springs may move springs, and wheels, indexes; but the motion and the regulation must be derived from the artist. Sounds may be produced by undulations in the air, undulations of the air by vibrations of musical strings; but the impulse and the melody must arise from the master."

[56] Sir Humphry Davy, in his *Elements of Chemical Philosophy*, page 180.

ESSAY II.

ON

TEMPERATURE.

PART II.

OF ARTIFICIAL TEMPERATURE.

HAVING proposed in this part of the Essay to treat of certain expedients for increasing and diminishing temperature, I shall begin with an account of the means which have been employed by different nations, and in different periods of the world, for producing fire.

FIRE has been known in some part or other of the world in all ages. In ancient times it was always employed in the rites of religion; it consumed the burnt offerings of the Patriarchs; it was kept continually burning in the Jewish tabernacle[1]; it

[1] "The fire shall ever be burning upon the altar; it shall never go out." *Leviticus* vi. 13.

[a] Fire was so generally considered as the image of life, that *lighted* torches were usually placed in the hands of the newly married; and at their deaths *extinguished* torches were placed upon their tombs. *Essai sur le Feu sacré, &c.* 8vo. Amsterdam, 1768.

was looked upon as the origin of life[2], the soul of the world[3], the symbol of Deity; and, considering it as the visible sign of an invisible Being, it has, from time immemorial, been actually worshipped by the Persians, and by some other Asiatic nations[4].

Notwithstanding, according to Pliny, fire was for a long time unknown to some of the ancient Egyptians; and when Eudoxus, the celebrated astronomer, showed it to them, they were absolutely in raptures[5].

The Persians, Phenicians, Greeks, and several other nations, acknowledged that their ancestors were once without the use of fire; the Chinese confessed the same of their progenitors. Pomponius Mela, Plutarch, and other ancient authors, speak of nations, who at the time they wrote knew not the use of fire, or had but just learnt it. Facts of the same kind are also attested by several modern relations.

The inhabitants of the Marian Islands which were discovered in 1521 had no idea of fire. Never was astonishment greater than theirs, when they saw it on the descent of Magellan on one of their islands.

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[2] The fable of Prometheus, who stole fire from heaven to animate his man, seems to have been founded on this idea.

[4] The sacred fire of the Vestal virgins, among the Romans, was beheld by them with little less than adoration. Numa built a temple to Vesta, the goddess of fire, which in after ages was rebuilt with great magnificence.

[5] Pliny, l. xvi. c. 40. Jonston's *Hist. of the wonderful Things of Nature*, folio, London, 1657, page 33.

At first they believed it to be a kind of animal that fixed itself to and fed upon wood. The inhabitants of the Philippine and Canary Islands were formerly equally ignorant. Africa presents us, even in our own days, with some nations in this deplorable state of ignorance [6].

The production of fire by collision, and the use of flint and steel [7], were probably known long before the time of Pliny; though the more ancient method of procuring fire was by rubbing two dry sticks one upon the other with violence [8]. The Indians fasten two pieces of wood together, and then putting another stick between them, they turn the latter swift like a wimble, and thus make the whole take fire. In Apulia they wrap a cane within some cords, and then drawing the cords backward and forward, the cane becomes ignited by the motion [9].

Fire is also to be procured FROM THE SUN by means of a double convex lens, a concave mirror, or by a combination of a number of plain mirrors [10].

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[6] Goguet's *Origin of Laws, Arts, and Sciences*, vol. i. page 72.

[7] The Laplanders begin their contracts of marriage with the fire and flint; for fire with them is the author of life; and the flint, say they, is eternal, for the treasure of fire within it never fails. *Scalig. Exerc.* 16, § 1. Jonston, page 33.

[8] A series of experiments on the heat produced by the attrition of different woods against each other may be seen in Nicholson's *Journal*, vol. viii. page 218; together with a table constructed on the said experiments.

[9] Jonston's *History of Nature*, page 34.

[10] By these means wood may be burned to a coal, even under water. Hoffman, with the assistance of a concave mirror made by Hoessen, fused the Hungarian asbestos into glass in three seconds. Hopson's *Translation of Weigleb*, page 66.

It was by some one of these expedients that Archimedes contrived to set fire to the ships of the Romans during the siege of Syracuse. And that this account is not fabulous, as some writers have imagined, is rendered probable, from the effects which have been actually produced by these contrivances in later ages[11]. The following instances will be sufficient to enumerate.

At the beginning of the last century Mr. Tschirnhausen, a member of the Royal Academy of Sciences, made several burning glasses, which were each three or four feet in diameter, and had a focus of one inch and a half diameter at the distance of twelve feet. One of these, which was convex on both sides, and weighed one hundred and sixty pounds, was used by M. Homberg, who communicated the result of his experiments to the Academy, and announced the following facts.

"All sorts of wood," says he, "though ever so hard or green, will be fired by this instrument in a moment. Water in a small vessel will boil immediately. Tiles, slates, pomice stones, grow red in a moment, and vitrify. Any metal, put into the crevises of a coal, melts in a moment. Lead and

[11] Father Kircher, and his pupil Schottus, visited Syracuse for the express purpose of investigating the truth of this story; and they proved by direct experiment that Archimedes, by a combination of mirrors, might easily have destroyed the fleet of Marcellus at the distance at which the ships must have lain from the walls of the city; and also the possibility of the success of Proclus, who is said to have destroyed a fleet at Constantinople in the same manner. *Phil. Trans.* vol. xlviii. page 621.

tin volatilize entirely. The ashes of herbs and wood become transparent glass in an instant[12]."

Another instrument and one that was still more powerful was constructed in the year 1773, under the direction of M. de Trudaine, and placed in the garden of the Infanta at the Louvre. It was composed of two large glasses, each four feet in diameter, joined at the edges so as to hold alcohol[13]. These glasses, which were without flaw, were two thirds of an inch thick, and formed two portions of a sphere of eight feet radius, leaving between them a vacuum capable of containing thirty-five French gallons of liquid. The focus of this instrument was at the distance of ten feet ten inches, when filled with alcohol; at eleven feet eleven inches when filled with distilled water; and at seven feet when filled with liquid turpentine. With this apparatus all the effects already mentioned were easily produced, and even the clippings of bar-iron were melted in an instant[14].

We are informed, however, by Mons. Buffon, who expended a very considerable sum in the construction of different instruments for concentrating the rays of the sun, that the only way by which the sun's rays can be made to produce an intense heat

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[12] *The History of the Works of the Learned*, 4to. London, 1702, vol. iv. page 655.

[13] In the *Gentleman's Magazine* there is an account of some interesting experiments, made with Mr. Villette's concave mirror, of forty-seven inches diameter. Vol. xliv. page 220.

[14] *The History and Memoirs of the Royal Academy of Sciences at Paris*, for the years 1774 and 1777.

at a great distance, is by the combination of a considerable number of plain mirrors, so disposed as to throw numerous images of the sun upon the same spot [15].

One of these instruments, which consisted of 360 plain mirrors, each eight inches long and six inches broad, mounted on a frame eight feet high, produced the following very powerful effects:

When twelve of the mirrors only were used, light combustible substances were kindled at the distance of twenty feet. At the same distance a large vessel of tin was melted by forty-five of these mirrors, and a thin piece of silver with 117 of them. With the entire machine all the metals and metallic minerals were melted at the distance of forty feet: and when the sky was clear, wood was kindled by it even at the distance of 210 feet.

In appreciating the comparative value of concave and plain mirrors, Mons. Buffon remarks, that as at the distance of fifty feet the focus, or space in which all the images coincide, is about seven inches broad, metals may be assayed by it, and other curious experiments made in the large way, which it is impossible to execute with concave mirrors, in which the focus is inconveniently near or weak, and generally a hundred times less than that produced by this machine.

Among other purposes for which this instrument may be employed, the author has stated that it

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[15] *Phil. Trans.* No. ccccIxxxiii. pages 493 and 495.

might be used with advantage in the manufacture of salt, by producing a quick evaporation of the salt-water, without the expense of fuel. An assemblage of twelve mirrors, each a foot square, will, he says, be more than sufficient to give a boiling heat to the liquor contained in shallow pans constructed for this purpose.

There are difficulties however in applying this instrument to purposes of general utility which must not be concealed. A cloud passing over the sun during some processes would be a great inconvenience; and when the sun does shine in its full splendour, the motion of the earth will prevent the focus from ever being kept for a minute at a time on one spot.

In describing the burning glasses made on the continent, I have been guilty of a great omission by hitherto neglecting to notice the burning mirror belonging to Sir Isaac Newton, which consisted of seven concave glasses, each of a foot in diameter; and the glass lens made by Mr. Parker, of Fleet-street, London, at an expense of 700*l.*, which was doubtless the most powerful burning lens ever constructed. The zero of Wedgwood's pyrometer was fixed by the inventor at the lowest red-heat visible in daylight: the greatest welding heat of iron by that instrument is 95°, and the extremity of the scale is 240°: but the power of the lens, estimated by this pyrometer, was found to be 1096°, which is a temperature that was never before obtained by any human being. In addition to these few par-

ticulars, I am desirous of stating that a very circumstantial account of this wonderful instrument has been drawn up by Mr. Parker, jun. for Rees's Cyclopædia, where it will be found, under the article "Burning Glass," in vol. v. part ii.

ELECTRICITY is also a means that may be mentioned when treating of the various methods of increasing the temperature of bodies, as it is capable of producing powerful effects. The electric matter collected by the friction of a glass plate or cylinder upon a prepared cushion [16] is received on a metallic conductor, as it is generated; and from thence it is conducted into a number of glass jars coated with tin-foil.

By the discharge of one of these electrical batteries [17], the combustion of various substances may be effected; animal life may be destroyed; and wires of the different metals will be melted in an instant. But notwithstanding these powerful effects, the electric matter may be thrown *gradually* upon the human body without producing any mischief or inconvenience whatsoever; as is constantly practised in cases of medical electricity. To this silent and

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[16] Electricity is best excited by rubbing the cushion with an amalgam of tin and zinc. The excitation seems to depend upon the ready oxidizement of the metals which form the amalgam; for such metals as are not easily oxidized produce no electricity.

[17] A memoir of Colonel Haldane on the method of measuring the force of an electrical battery, during the time of its being charged, will be found in Nicholson's *Journal*, 4to, vol. i. page 156.

harmless employment of the electrical fluid, one of our modern poets refers in the following lines:

> "For if on wax some fearless beauty stand
> And touch the sparkling rod with graceful hand,
> Through her fine limbs the mimic lightnings dart,
> And flames innocuous eddy round her heart."

By VOLTAIC ELECTRICITY, or galvanism, much more powerful effects may be produced in igniting various substances, and in melting metals, than have ever been occasioned by simple electricity. These, however, depend much on the size and the nature of the apparatus; and though most persons may be acquainted with this property of galvanism, it is impossible for any one to form an adequate idea of the power which may be acquired by an extensive apparatus, in which there is a proper combination of number of plates, and an extended surface, unless he actually witnesses some of the effects produced by it.

"The grandest combination," says Sir H. Davy, "ever constructed for exhibiting the effects of extensive surface *alone*, was made by Mr. Children: it consists of twenty double plates four feet by two; of which the whole surfaces are exposed in a wooden trough, in cells covered with cement, to the action of diluted acids. This battery, when in full action, had no more effect on water, or on the human body, than one containing an equal number of *small* plates; but when the circuit was made through me-

tallic wires, the phænomena were of the most brilliant kind."

"A platinum wire of one thirtieth of an inch in thickness, and eighteen inches long, placed in the circuit between bars of copper, instantly became red hot,—then white hot;—the brilliancy of the light was soon insupportable to the eye; and in a few seconds, the metal fell into globules [18]. Points of charcoal ignited by this power, produced a light so vivid, that even the sun-shine, compared with it, appeared feeble."

"But the most powerful combination that exists, in which number of alternations is combined with extent of surface, is that constructed, by the subscriptions of a few zealous cultivators and patrons of science, in the laboratory of the Royal Institution. It consists of two hundred instruments, connected together in regular order, each composed of ten double plates arranged in cells of porcelain, and containing in each plate thirty-two square inches; so that the whole number of double plates is 2000, and the whole surface 128,000 square inches.

"This battery, when the cells were filled with sixty parts of water mixed with one part of nitric and one part of sulphuric acid, afforded a series of brilliant and impressive effects.

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[18] To form an adequate idea of the power of this apparatus, it should be recollected that platinum cannot be melted in the most intense heat of an air furnace, nor in a smith's forge, unless oxygen gas be employed; and yet by the silent action of galvanism it became, in this instance, fused in a few seconds.

"When pieces of charcoal, about an inch long and one-sixth of an inch in diameter, were brought near each other, within the thirtieth or fortieth of an inch, a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness; and by withdrawing the points from each other a constant discharge took place through the heated air, in a space equal at least to four inches, producing a most brilliant ascending arch of light, broad and conical in form in the middle.

"When any substance was introduced into this arch, it instantly became ignited; platinum melted as readily in it as wax in the flame of a common candle; quartz, the sapphire, magnesia, lime, all entered into fusion; fragments of diamond, and points of charcoal and plumbago, rapidly disappeared, and seemed to evaporate in it, even when the connexion was made in a receiver exhausted by the air pump; but there was no evidence of their having previously undergone fusion [19]."

The CLOUDS may be considered to be another source from whence man has the means of procuring fire. The first idea of the identity of lightning and electricity occurred to the mind of Dr. Franklin in the year 1752; and in the month of June in that year, he elevated a kite for the purpose of ascertaining the fact, and on the first trial he had the satis-

[19] Sir Humphry Davy's *Elements of Chemical Philosophy*, page 151.

faction of finding his conjecture verified and the discovery complete[20].

In the following year the experiment was repeated in France, and on a large scale, by Mons. Romas, which fully demonstrated the powerful effects of elevated metallic conductors in drawing off the electric matter.

The kite which he employed had a wire interwoven in the hempen string, and the following were some of the signs of electricity which it exhibited soon after its elevation in the atmosphere. "Electrical sparks three inches long and a quarter of an inch thick were drawn at the distance of a foot from a tin conductor, connected with the apparatus, the snapping of which was heard at 200 paces. On the falling of a little rain, the appearances increased amazingly, and a continual rustling noise was heard, like that of a small forge bellows."

The remainder of the account which Dr. Priestley has given of these very interesting experiments[21] is too long to be introduced here; but I have no hesitation in saying that those of my readers who may have an opportunity of seeing the work, cannot fail of being highly gratified by its perusal.

By this discovery of Dr. Franklin's we have learnt how to secure houses and other more elevated buildings, and ships at sea, from damage by lightning; and are taught that a very small metallic con-

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[20] Priestley's *History of Electricity*, 4to. London, 1767.
[21] *Ibid.*

ductor, if elevated above the highest part of an edifice, and connected with the earth, is capable of conveying a very large quantity of electric matter from the clouds to the earth, without noise, and without leaving any signs of its having been present.

Those who may be desirous of repeating the experiments with an electrical kite, ought, however, not to attempt the thing without the utmost caution, and a thorough knowlege of the science of electricity, lest they should share the fate of Professor Richman, who through mere inadvertence lost his life, in the midst of his family, during a series of experiments similar to those of which we are now speaking.

This ingenious and indefatigable man, who was professor of natural philosophy at Petersburg[22], had elevated an insulated metallic rod, and prepared a considerable apparatus[23] to collect the aërial electricity, as Dr. Franklin had previously done at Philadelphia; and as he was observing with Mr. Sokolow, engraver to the Royal Academy at Petersburg, the effects of the electricity upon the balls of his electrometer, during a thunder storm on the 6th of August[24], 1753, he approached too near the

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[22] Professor Richman was born on the 11th of July 1711, after the death of his father, who was treasurer to the king of Sweden. He was made a member of the Imperial Academy in 1735, and professor of experimental philosophy in 1745.

[23] An engraving, and an ample description, of the apparatus employed by Professor Richman may be seen in the xlviiith vol. of the *London Philosophical Transactions*; also a drawing of the

conductor, and was instantly struck dead by the side of his philosophical friend, who received no injury.

The deceased was attending the usual meeting of the Academy, when hearing it thunder at a distance, he hastened home, in company with Mr. Sokolow, to witness its effects upon his apparatus, and in less than an hour he became a corpse.

The explosion which attended this dreadful catastrophe, was as loud as the report of a pistol; the stroke was given at a foot distance from the rod; and from the description of Mr. Sokolow, the electrical spark which struck the professor must have been of a size several inches in diameter. The metallic rod was broken in pieces; and the melted fragments being thrown upon Mr. Sokolow's clothes, left the mark of their form and dimensions upon them.

The professor had seventy rubles of silver in his left coat-pocket which were not in the least altered. But a clock which stood in an adjoining room was stopped, the door of one of the chambers of the house was broken, and the ashes which lay upon the hearth, were forced from thence into the middle of the room.

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apartments of the house, marking the room and the exact situation in which the professor stood when he received the fatal stroke.

** In the xlviiith vol. of the *Philosophical Transactions*, the 6th of August is given as the day on which this accident happened; —but in the xlixth vol. of the *Transactions* it is said to have occurred on the 26th of July: probably one is calculated from the old, the other from the new style.

Mrs. Richman, on hearing the loud stroke of the thunder, hastened into the chamber, and found her husband past sensation, sitting upon a chest, which happened to be placed behind him, and leaning against the wall, which situation must have been occasioned by his falling back upon receiving the electrical charge. He was no sooner struck, than killed. There were not the least appearances of life. The surgeons opened a vein of the breathless body twice, but no blood followed. They endeavoured to restore sensation by violent friction, and by other expedients, but in vain [25].

COLLISION is another means of procuring fire. When fire is produced by COLLISION, particularly when flint and steel are the media, it arises from the sudden extrication of the *latent* caloric which is forced out by percussion, then becoming free and perceptible to our senses. It was first suggested by Mr. Hume [26], and his opinion is now found to be correct, that oxygen exists in a very large proportion and in a most condensed state in flint and all other siliceous stones. Were, I, therefore, to hazard a

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[25] *Philosophical Transactions*, vol. xlviii. page 765, and vol. xlix. page 61.

When RICHMAN rear'd, by fearless haste betray'd,
The wiry rod in Nieva's fatal shade;
Clouds o'er the Sage with fringed skirts succeed,
Flash follows flash, the warning corks recede;
Near and more near HE eyed with fond amaze
The silver streams, and watch'd the sapphire blaze;
Then burst the steel, the dart electric sped,
And the bold Sage lay number'd with the dead!

theory upon the phenomena that take place in this instance, I should say,——the latent caloric thus set free had been previously combined with the steel, and perhaps with this condensed oxygen; and that the new compound, the spark which flies off, and is oxide of iron, requiring less latent heat for its composition, permits what is now superfluous to become *free* and active, and to pass to the tinder, gunpowder, or any other combustible substance to which it may be exposed.

This application of flint and steel to each other has lately been employed not only for procuring fire, but for another very important purpose.

The late Mr. Spedding, who was an engineer to some large collieries in the North of England, having observed that the coal-damp could only be kindled by flame, and was not liable to be set on fire by red-hot iron, invented a machine, in which, while a steel wheel is turned round with very rapid motion, flints are applied to it, and by the abundance of sparks emitted, the miners are enlightened, and enabled to carry on their work in places where the flame of a lamp or candle would be likely to occasion dreadful explosions [27]. Without some inven-

[26] In the first edition of *The Chemical Catechism*, 8vo, 1806, page 151, and *Philosophical Magazine*, vol. xxx. page 165.

[27] Mr. Beaumont, writing on the collieries near the Mendip hills, says, "Scarce a pit fails having this fire-damp, yet our colliers still pursue their work. To prevent mischief, they keep their air very quick, and use no candles in their works but of a single wick, and those of sixty or seventy to the pound, which nevertheless give as great a light there as others of ten or twelve

tion of this sort, the working of such mines would have been utterly impracticable[28].

Phosphorus may be mentioned as another agent by which fire may be produced extemporaneously, at any hour and in any season. All that is necessary is to rub a few grains of it for a second or two, with a match or other small piece of wood, upon a piece of cork, when inflammation will quickly take place, and continue till the whole of the phosphorus be consumed. This peculiar substance is chiefly of animal origin, though it be still doubtful whether it is not originally derived from the mineral kingdom, and thence passes to vegetables, and so on to the animal system, where it is most abundant.

Phosphorus was discovered either by Brandt or Kunkel about the year 1669. The product of its combustion is either phosphorous or phosphoric acid, according to the quantity of oxygen absorbed, and to the mode in which the combustion has been conducted.

Fire may also be procured with great facility from a saline compound called CHLORATE OF POTASH, formerly HYPER-OXY-MURIATE OF POTASS. If this

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to the pound in other places, and they always fix the candles behind them, and never present them to the breast of the work." *Philosophical Collections* for the years 1679 to 1682, published by the Royal Society of London, page 7.

[28] A more particular account of this expedient may be seen in *The Tradesman's Magazine*, vol. ii. page 445.

salt be intimately mixed with any of the highly combustible substances, and the salt be then decomposed, fire and combustion will be the consequence.

A preparation of this sort may very conveniently be made by mixing some of the salt with about an equal portion of loaf sugar, both in fine powder. This is a mixture which may be kept ready prepared and preserved in a phial for any length of time, with perfect safety. Whenever fire is required, all that is necessary is to put a few grains of this mixture upon a bit of tile or on a plate, and then to drop upon it the most minute quantity of concentrated sulphuric acid, which will occasion an immediate burst of flame, increasing in size until the whole mass enters into actual combustion.

A composition of this kind has been lately employed instead of sulphur for coating the ends of matches; and these are more convenient for procuring fire, or an instantaneous light, than any thing which has ever before been offered to the public. In using them, all that is necessary is to dip the coated end of one of them into sulphuric acid, or into a phial of asbestos impregnated with that acid, and it will take fire immediately. The asbestos is put in merely to prevent the acid from spilling, as cotton is put into a common inkstand. The fire in this case is produced in consequence of the decomposition of the hyperoxymuriatic salt by the sulphuric acid, which seizes the base of the salt, and liberates the chloric acid, which also becomes decomposed, and occasions this curious phenomenon.

By mixing this salt with other combustibles, such as sulphur and charcoal, in proper proportions, a preparation will be formed which will inflame merely by percussion or friction; and an ingenious Scotch chemist, the Rev. Alexander Forsyth of Belhelvie, has taken advantage of this property of the chlorate of potash, and employed it in the manufacture of a new kind of gunpowder, for which he obtained a patent, and which, for the use of sportsmen and some other purposes, is preferable to common gunpowder. An eighth of a grain of it is sufficient for priming a fowling-piece or a musket, and this of itself makes a very loud report [29]. Before Mr. Forsyth obtained his patent, M. Berthollet had proposed to manufacture gunpowder with this salt for the use of the French army; but no sooner did the workmen begin to triturate it than it exploded violently, and occasioned the death of several persons. Notwithstanding this accident, gunpowder made with chlorate of potash was some time afterwards employed by the French army in one of their campaigns.

To these methods of procuring fire may be added that of COMPRESSION. It is a general maxim in

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[29] A more particular account of this new gunpowder, and which I received myself from the patentee, will be found in *The Chemical Catechism*, Additional Notes, No. 56: and an account of several curious experiments with the chlorate of potash, will be found in the tenth edition of the same work, pages 191 and 505.

chemical science, that extension and rarefaction occasion cold, but that condensation and compression generally produce heat.

This principle is well exemplified in a machine erected at one of the mines in Hungary. In this appparatus the air within a large cylinder is very forcibly compressed by a column of water 260 feet high. Therefore, whenever a stop-cock which is attached to the lower part of the cylinder is opened, the compressed air rushes out with great violence, and its expansion is so sudden and considerable that the moisture which was contained in the compressed air is immediately condensed, and falls in a shower of snow [30].

Some time ago a soldier in the French army discovered that light and heat may be produced merely by the compression of atmospheric air. This curious discovery has been acted upon in various parts of Europe, and is likely to become applicable to a variety of purposes. By adapting a moveable air-tight cap to the bottom of a common syringe, and placing within it a small piece of perfect tinder, and then depressing the piston with a sharp quick motion, heat will be produced sufficient to inflame the tinder. The use of the screw cap at the end of the syringe, is not only to render the instrument air-tight, but for the purpose of receiving the fungus or the tinder to be placed within it.

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[30] Dr. Wolfe has given a drawing and an ample description of this machine in *Phil. Trans.* vol. lii. page 547.

These syringes are now sold by most of the philophical-instrument-makers in London; and since their exhibition, it has been proposed to make walking-sticks furnished with similar syringes, (though for this purpose these syringes must be inverted,) and so contrived that a single stroke of the walking-stick on the ground would be sufficient to inflame the tinder, and afford the traveller a light in any emergency.

There is another mode of procuring fire, viz. by PERCUSSION. Nothing is more common in some countries, where fuel is dear and fires are not kept up during the night, than for a smith to procure a light in the morning by laying a bar of iron across an anvil and hammering it incessantly till it become hot enough to set fire to tinder. Here, a portion of the caloric which is naturally latent in the iron, and tends to give it malleability, is forced out by the continued hammering, and becomes free and efficient heat.

FRICTION, which seems to be only a succession of percussions, will also produce intense heat. Mr. Thomas Wedgwood held the edge of a piece of window-glass against the surface of a revolving grit stone, and the part in contact with the stone became red hot and threw off particles which fired gunpowder. Philos. Trans. for 1792, pages 45 and 270. Since then Count Rumford suspended a metallic cylinder within a quantity of cold water measuring

eighteen pints, and caused it to revolve, pressing against a boring instrument, at the rate of thirty times in a minute; and in the course of two hours and thirty minutes it generated heat enough to make the water actually boil [31].

It is also possible to produce combustion by the mere MIXTURE of some fluids. Thus, if certain proportions of nitrous and sulphuric acid be poured into the essential oil of turpentine, a rapid combustion and inflammation will be occasioned. This, however, is not a very safe experiment, unless it be conducted with caution and prudence.

It may also be mentioned, that if either POTASSIUM or SODIUM be placed upon ice, fire will be produced, and the metal by this combustion will be converted to an alkali [32].

Combustion often occurs spontaneously by the DECOMPOSITION OF WATER; of this we have many instances. Hay, clover, weld, or other vegetables, if put up in ricks before they are properly dried, are very apt to ferment, and occasion spontaneous combustion. Substances that are thoroughly impregnated with animal or vegetable oil, when laid up damp and in large heaps, are also very likely to take fire of themselves from the decomposition of the water and the oil. This happens sometimes to

[31] See an Inquiry concerning the Source of the Heat which is excited by Friction in the *Phil. Trans.* for 1798, page 80.

[32] *Phil. Trans.* for 1808, pages 13 and 14.

painted oil-cloths, and likewise to woollen cloths[33], which have been laid up moist, and in heaps, without having the oil removed which had been employed in dressing them. There are also examples of cotton taking fire by being improperly laid up[34]; and the spontaneous firing of a mixture of lamp-black and oil is well known[35]. I believe it is also no very uncommon thing for buildings to be burnt down in consequence of quick lime being incautiously stored in them, and water getting access to it.

Again, *peat* laid up in very large heaps for fuel is disposed to take fire[36]; and in coal countries it is universally known that if pyritous coal be stacked without having the martial pyrites previously picked out, there is great danger that the first shower of rain may produce heat enough to set fire to the whole mass[37].

This combustion of pyritous coal is probably the

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[33] There is a singular account of the spontaneous decomposition of a fabric of silk, in the *Philosophical Magazine*, vol. xvi. page 92.

[34] Dr. Henry accounts for the fires which have sometimes happened in cotton-mills, from the waste cotton, employed to wipe the oil from machinery, having been laid in heaps sufficiently large to occasion combustion. Henry's *Chemistry*, vol. ii. page 162.

[35] There have been instances in which carburetted earths, being mixed with linseed oil for the purpose of making paints, entered spontaneously into a state of combustion. *Gentleman's Magazine*, vol. xxi. page 71, and vol. xxii. page 82.

[36] Berthollet *On Dyeing*, vol. i. page 177.

[37] Dr. Plot relates the case of a person at Ealand in Yorkshire who piled several cart-loads of martial pyrites in a barn, of which the roof being faulty, the rain came upon them, set fire

cause of many of the subterranean fires which appear in every quarter of the globe. Near Baku in Persia, the inflammable vapour which issues from the earth is so considerable that the inhabitants burn their lime by its means. There is a caravansary[38] built on the spot, and in this live twelve Indian priests and other devotees who worship this fire, which, according to their traditions, has burnt many thousand years[39].

Dr. Plot speaks of a district near the Staffordshire collieries which was on fire in his time[40]. This spot I have myself visited more than once, and the mass of coal within the bowels of the earth is still burning, and probably will not cease for ages yet to come. The poor inhabitants of that neighbourhood call it the *fiery ground*, and felicitate themselves in living so near it, as many of them make

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to the building, and occasioned an alarm for the safety of the whole town. Plot's *Staffordshire*, page 142.

Dr. Jorden mentions that a heap of coals once took fire at Puddle Wharf, London, in consequence of pyrites being mixed with them. Jorden *On Mineral Waters*, chap. 14.

[38] "This is a very old vaulted building, and in its walls are many chinks, whereto if a candle be applied, the fire catches instantaneously, and runs wherever the chinks communicate. They have hollow places in the house fitted to their pots, where they boil without any other fuel; and instead of candles they stick reeds into the ground, from the tops whereof, upon applying fire thereunto, a white flame comes forth, and continues to burn without consuming the reeds, until they think proper to extinguish it, by putting little covers over them for that purpose." *Phil. Trans.* vol. xlv. page 296.

[39] Other curious particulars respecting this subterranean fire may be seen in Mr. Jonas Hanway's *Account of his Travels through Persia*.

[40] Plot's *History of Staffordshire*, chap. iii. page 141, § 53.

considerable sums of money, early in the year, by the produce of their gardens, which are always some weeks forwarder than any other in that part of the kingdom. Some of the esculent vegetables flourish surprisingly on this spot;

"Where, in basaltic caves imprison'd deep,
Reluctant fires in dread suspension sleep;
Or sphere on sphere in widening waves expand,
And glad with genial warmth the incumbent land[41]."

I have mentioned elsewhere that His Majesty's ship Ajax is supposed to have been destroyed in the Mediterranean entirely by the sudden combustion of a heap of pyritous coal, then on board for the use of the ship. I also noticed that a friend of mine had a serious accident from the spontaneous inflammation of a mixture of hyperoxymuriate of potass, charcoal, and sulphur.

All such accidents may be explained, by referring them to the decomposition of water, and the inflammation of its hydrogen. But there are instances on record of another kind of spontaneous combustion, which is not so well understood, viz. that of the human body absorbing oxygen with such rapidity as that the whole became silently consumed to ashes[42]; and this, independently of any outward

[41] There is a fountain near Grenoble in Dauphiné; another in Transylvania; a third near Chermay, a village in Switzerland; a fourth in the canton of Friburg; and a fifth not far from Cracow in Poland, the waters of which give out gases that will take fire and burn. Campbell's *Political Survey*, vol. i. page 73.

agent, to which the commencement of the combustion could possibly be attributed.

Several cases of this kind have been described and well authenticated [43]; though it is remarkable that this has never been known to have happened to any but females, and all these were persons who had long indulged themselves in an inordinate use of spirituous liquors [44].

The means which have been employed in different parts of the world for MODIFYING the effects of HEAT AND COLD, have been so various, that I can only attempt to enumerate a very small proportion of them. But I shall select those which I do not consider to be very generally known, or such as may probably be applied, though in a different way, to some useful purpose in this country.

If we begin with that part of the subject which refers to the MODIFICATION of HEAT, or the reduction of temperature, it must be remarked that this is often effected on different principles, according to situation and circumstances.

In some cases the principle of producing cold by

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[43] There is an account of a great variety of cases of spontaneous combustion, in the 18th volume of the *Phil. Mag.* extracted from a memoir by Mons. Bartholdi in one of the volumes of the *Annales de Chimie*.

[43] *Phil. Mag.* vol. vi. page 132; *Gent. Mag.* vol. vi. p. 647.

[44] The curious case of the Countess Cornelia Zangari, also of Bandi of Ceséna, of Grace Pet at Ipswich, whose body is said to have been burnt to a cinder, and of a woman at Paris, may all be seen in *The Gentleman's Magazine*, vol. vi. page 647, and *The Philosophical Transactions*, vol. xliii. page 447.

EVAPORATION is resorted to. Thus in India, where the apartments are separated from their courts by curtains instead of walls, slaves are employed in perpetually sprinkling these curtains with water, the evaporation of which, when constantly kept up, will reduce the temperature of the rooms ten or fifteen degrees.

The alcarazas of Spain for cooling wine act on the same principle. These, which are very porous earthen vessels, are prepared for use by soaking them in water for a considerable time, so as to saturate them with that fluid. Within these earthen jars vessels containing the wine are introduced, and the perpetual oozing and evaporation of the water[45] cools the interior of the vessel, and consequently reduces, in some measure, the temperature of the wine or other liquor placed within it.

These, however, at least all that I have seen, are ill calculated for the purpose; for, being so much larger than necessary, a sheet of air of the temperature of the room envelops the wine bottle, and prevents the proper action of the alcaraza upon it; whereas, if they were made perfectly cylindrical, in-

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[45] The ice-makers at Benares discard all those vessels in which the pores have become stopped by long use, and they find that if the water be exposed in porcelain vessels, no ice is produced. *Universal Magazine* for 1793, page 420.

[46] As these utensils lower the temperature of wine only a few degrees, it would be a much more effectual method of cooling, merely to plunge the bottles into a vessel of water recently drawn from a very deep well. Indeed, I once knew a gentleman who sunk a large well on purpose to store his port wine in, and he

stead of being bulged, and no larger than just sufficient to admit a bottle of wine within them, they would be much better refrigerators than those which are usually sold for this purpose[46].

This principle of cooling by evaporation is well understood by the caravans who cross the great desert of Arabia. These people have occasion for a large quantity of water, which they carry with them on camels, in bottles of earthen-ware, and which, in passing over the burning sands of that country, would become very disagreeably hot, were it not for the following expedient, which is universally adopted by them. When they lay in their stock of water, each bottle is infolded in a linen cloth, and some of the company are appointed to keep these cloths constantly wet[47] during the journey; by which means a perpetual evaporation is produced, and the contents of the bottles are preserved at a cool and refreshing temperature.

In like manner, in the nights in Bengal, when the temperature is not below 50°, by the exposure of water in earthen pans upon moistened bamboos, thin cakes of ice are formed, which are heaped to-

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assured me that he found it to be a very advantageous mode of keeping it.

[47] Athenæus relates, that in Egypt the pitchers filled with water, which had become warm by standing all day long in the sun, were kept continually wet during the night by servants destined to that office; and in the morning, to preserve the water at the cool temperature to which this expedient had reduced it, the pitchers were bound round with straw. *The Deipnosophists*, iii. page 124.

gether and preserved under ground by being kept in contact with bad conductors of heat[48].

In performing some delicate chemical experiments, the application of this principle may be found extremely useful. Thus, any fluid body which has been heated by mixture or otherwise, may, in a few minutes, be brought to the desired temperament by frequently wetting the containing vessel with ether, which, by the rapidity of its evaporation[49], and consequent abstraction of caloric, instantly lowers the temperature.

Should any one doubt the efficacy of evaporation in producing cold, let him suspend a thermometer in the air, and, having wet the bulb with ether once or twice, notice its operation as indicated by the scale of the instrument.

Evaporation is also a drying as well as a cooling process. When I have wanted a bottle in haste to be thoroughly dry, for taking specific gravities or any other nice philosophical purpose, after washing it with water, and draining that out as well as I could, I have rinsed it with a little ether, and it has been dry in an instant.

But the more ancient, and perhaps the most universal mode of reducing the temperature of bodies,

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[48] Sir Humphry Davy's *Chemical Elements*, page 88.

[49] For an account of an expeditious mode of producing ice by the evaporation of sulphuric ether, see *Phil. Trans.* for 1795; or *Monthly Review*, New Series, vol. xxi. page 299.

[50] "As the cold of snow in the time of harvest, so is a faithful messenger to them that send him: for he *refresheth* the soul of his masters." *Proverbs* xxv. 13.

was by means of ICE and SNOW. That these were used for this purpose in the time of Solomon, we have the testimony of some of the most ancient writings[50]; and we are told that Alexander the Great, when he lay before the besieged city of Petra, having an eye to the delicacies of his table, caused thirty trenches to be dug, and filled with snow, which was defended from the sun by oak branches, and preserved for a long time in the state required[51].

The snow of Lebanon was in high estimation in the days of the prophet Jeremiah[52]; and according to Mr. Harmer, the present inhabitants of Palestine collect snow during the summer months, from the top of the same mountain, and carry it two or three days journey, "that, being mixed with their wine[53], it may keep it as cold as ice[54].

The celebrated Abbé Nollet, who drew up a memoir on the means of supplying the want of ice in warm countries, advises the keeping of wines and other potable liquors in the following manner, in preference to keeping them in wells, cisterns, or cellars. He recommends the digging a hole in the earth about four feet deep, in which the liquor should be placed in bottles, covering them over with a foot of earth, dug from the bottom of the hole,

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[51] *Athenæi Deipnos.* iii. 124. Beckman, vol. iii. page 344.

[52] Jeremiah xviii. 14.

[53] According to the writer of the *Travels of Anacharsis*, the ancient Athenians usually mixed a small quantity of sea water also in their wine.

[54] Harmer's *Observations on divers Passages of Scripture*, Clarke's edition, vol. ii. page 156.

and moistened with a little water, after which he advises the covering up the mouth of the hole with a plank, strewed over with new dug earth[55]. In adopting this method, it will be essential not only that the liquor should be put into the thinnest bottles, but also that these should be of such a form as to afford the greatest quantity of surface to the refrigerating agent. Hence several thin glass bottles will be much better than one larger bottle of thick glass.

Ice and snow in hot countries being applicable to so many useful purposes[56], it was natural for mankind to devise some expedient whereby they might have these articles in all seasons. Hence ice-houses were built, but the era of their invention is not known. That the ancient Romans were acquainted with them is evident from the writings of Pliny, who passes this severe censure upon them:

"Hi nives, illi glaciem potant, pœnasque montium in voluptatem gulæ vertunt: servatur algor æstibus, excogitaturque ut alienis mensibus nix algeat[57]."

It appears, however, that the practice of cooling

[55] *History of the Royal Academy of Sciences at Paris*, for the year 1756.

[56] Thomas Bartholin, physician to the king of Denmark, published a *Treatise on the medicinal uses of snow*. Copenhagen, 8vo, 1661.

[57] Lib. xix. c. 4. Martial in one of his epigrams sports with it thus:

"Non potare nivem, sed aquam potare rigentem
De nive, commenta est ingeniosa sitis."

MART. xiv. Ep. 114.

liquors, at the tables of the great, was not usual in any country of Europe, excepting in Italy and the neighbouring states, before the end of the sixteenth century: and there is a direct testimony on record, that in the middle of that century there were no ice-cellars in France[58]. However, before the end of the seventeenth century the luxury of ice was very common in France; for about that time there were many persons who were professed dealers in snow and ice; and Quintine, the celebrated French gardener, relates that once, when no ice could be procured on account of the great mildness of the preceding winter, the merchants at Hamburg sent a ship to Greenland for a load of it, by which they acquired great profit[59]. In 1676 there were not less than two hundred and fifty shops, in Paris alone, for the sale of liquors of different sorts cooled with ice[60].

In regard to the receptacles for ice, I have not met with any account of the mode in which the ancient Romans constructed their ice-houses, and therefore I can give only a few particulars respecting the modern practice.

In the first volume of the Philosophical Transactions, to which I am indebted for the passages which I have just quoted from Pliny and Martial, I find the following sentence: "The usual way in Italy and other countries, to preserve snow and ice, is set

[58] Beckman's *History of Inventions*, vol. iii. page 356.
[59] *Instruction pour les Jardins*, Paris, 1730, 4to, i. p. 263.
[60] Beckman, vol. iii. p. 362 and 378.

down so punctually by Mr. Boyle, in his History of Cold, that nothing," says the author of the paper, "is to be added[61]." I have cursorily examined Mr. Boyle's work, and am indebted to it for some curious information: but my copy is probably a different edition from that used by the writer of this article, for I cannot discover the relation to which he alludes; and Mr. Boyle's treatise on cold is printed so close, and contains so much abstruse and obsolete matter, that rather than employ unnecessary time in labouring through so many uninteresting pages, I merely mention it, that others may, if they please, avail themselves of the information.

At Leghorn and in other places in that neighbourhood, they lay the bottom of their ice-pits with a thick covering of corn chaff; and as the ice is placed within them, the chaff is brought up all round the sides, and when the pits are full they are well covered up with the same article. Whenever it is necessary to remove any of the ice to a distance from these pits, it is infolded in similar chaff, and is thus preserved from melting[62].

Sir Robert Barker has given a very particular account of the method of making ice at Calcutta and other parts of the East Indies lying between 25½ and 23½ degrees north latitude, where natural ice is never seen. But I shall refer my readers to the paper itself for particulars[63]; and also to any of the mo-

[61] *Philosophical Transactions*, vol. i. p. 140.
[62] *Id. ibid.* p. 139.
[63] *Id.* vol. lxv. p. 252.

dern Encyclopedias for an account of the present mode of building ice-houses in England, as a full description of them is not compatible with my present plan.

Olearius, in an account of his journey to Muscovy and Persia, relates that at Ispahan the inhabitants have conservatories, which they furnish with solid pieces of ice of a good thickness, only by pouring water at night, at certain intervals, upon a sloping floor of freestone or marble, where it becomes frozen and attached to the former coat of ice, and in two or three successive nights is brought to a very considerable thickness.

The late Mons. Fourcroy, when treating of temperature, remarks, that "chemists often avail themselves of the privation of caloric, in order to prevent the effect of chemical action[64]; to impede the too powerful energy of solutions, combinations and decompositions; or to prevent those spontaneous changes which do not fail to take place in certain compounds, if they remain for a time exposed to a temperature sufficiently elevated to favour the mutual action of their principles. By these means, namely, by a cold temperature, vegetable and animal substances are preserved; and thus it is that

[64] There is a curious memoir by Gren, in the 27th number of the *Journal des Mines*, on the formation of sulphate of soda in salt waters, and upon an easy method of disengaging all the deliquescent salts, at a temperature beneath the freezing point of water. An abridgement of this paper is also printed in the 24th volume of the *Annales de Chimie*, p. 121, and in Nicholson's *Journal*, 4to, vol. ii. page 91.

an ice-house is scarcely less useful to the chemist[65] than a furnace at its different degrees of heat[66].

"In Tibet the inhabitants adopt the practice of preparing their meat by extreme cold. The process is extremely simple. They kill, clean, and strip the animal of his skin; he is then placed upon his legs in a commodious place, and left exposed to a free access of frosty air, until all the juices in his body are completely dried up, and the whole becomes one uniformly stiffened substance. It is then in a fit state for carriage to any part of Tibet, and for keeping to any season of the year. No salt is used in the preparation. I had supplies of this prepared meat, during all the time I remained at Teshoo Loomboo, which had been cured in the preceding winter. It was perfectly sweet, and I was accustomed to eat heartily of it, *without any further dressing*, and at length grew fond of it. It had not the appearance of being raw, but resembled in colour that which has been well boiled. It had been deprived of all ruddiness, by the intense cold[67]."

Captain James, whose ship was frozen up all the winter in one of the coldest regions of the world, writes thus: "We got up our five barrels of beef and pork, and had four butts of beer and one of cyder, which God had preserved for us: it had lain

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[65] Many uses of cold might be mentioned. Stone bottles grown musty by use, if partly filled with water, and the water thoroughly frozen, become as sweet as ever they were. Boyle, *Appendix*, page 12.

[66] Fourcroy's *System of Chem. Knowledge*, vol. i. page 190.

[67] Turner's *Embassy to Tibet*, 4to, London, 1806, p. 301.

under water all the winter, yet we could not perceive that it was any thing the worse [68]."

As it is well known that some decompositions take place at a temperature below 32°, which cannot be effected at one more elevated, it might be worth while for a chemist who has access to an ice-house, to institute a series of experiments, in order to determine the affinities of the simple substances, and some of their compounds, when submitted to the action of intense cold.

It may also be worth while to inquire whether an ice-house might not be employed with advantage during the summer months in preserving meat [69]. The Hon. Mr. Boyle relates that the physician to the Emperor of Russia assured him that he had had the venison of elks sent him unsalted, and yet untainted, out of Siberia, which is some hundreds of leagues distant from Moscow, and that beef and other flesh well frozen would keep for a very long time uninjured; and that it will have lost none of its natural flavour, provided it be very gradually and thoroughly thawed, before it be dressed for the table [70].

We know that from the salmon fisheries in Scotland and the north of England, the fish are sent to

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[68] T. James's *Journal*, page 74.

[69] "At Spitzburg the extreme cold will suffer nothing to putrefy and corrupt, insomuch that buried bodies are preserved entire for thirty years, and inviolated by any rottenness." Bartholinus *de Usu Nivis*, cap. 12.

[70] *Experiments on Cold*, 4to, London, 1683, page 85.

the metropolis, during the greater part of the season, packed with ice, in boxes about four feet long and eighteen inches deep. When packed, the ice, which is previously broken as small as bay-salt, is put over them and beaten down as hard as can be without bruising the salmon. In this manner they are kept perfectly fresh for two or three weeks[71].

There is another way of modifying heat which has not yet been adverted to, and which is comparatively of late invention. I refer to the use of certain SALINE BODIES, which absorb a large portion of caloric during their solutions, and consequently produce a great degree of cold.

The salt which was originally used for this purpose was nitre, and the Italians were the first people by whom it was employed. About the year 1550, all the water as well as the wine drunk at the tables of the great and rich families at Rome was cooled in this manner. It was customary to place the bottle containing the wine within a larger vessel of water, and into this they gradually put as much saltpetre as is equal to one-fourth or one-fifth of the weight of the water, and during its dissolution the bottle was driven round by the hand with a quick motion on its axis, in one direction[72].

After this, other salts were employed; and Lord

[71] *The Tradesman's Magazine*, vol. ii. page 520.

[72] Beckman, vol. iii. page 363.

[73] The iced creams are now, I believe, usually made by plunging the vessel of cream into a mixture of bruised ice and common salt.

[74] *Historia Vitæ et Mortis*, § 44. *Silva Silvarum*, cent. i. 83.

Bacon, who died in 1626, asserted that, by a mixture of snow with common salt [73], he could freeze water [74]. In the Mineralogy of Aldrovandus, first printed in 1648, it is said "that it was usual in countries where fresh water was scarce, to make deep pits in the earth, to throw rock-salt into them, and to place in them vessels filled with water, in order that it might be cooled."

When snow is mixed with common salt, both substances soon become in some measure liquid [75]. Now it is well known that solids can never become fluid without heat being absorbed, and consequently cold produced: therefore the abstraction of that portion of free caloric from the materials which is necessary to produce fluidity [76], is sufficient to account for the formation of ice in a fluid that is immersed in it.

Towards the latter end of the seventeenth century, Mr. Boyle made experiments with various kinds of salts and other substances for reducing the temperature of water, and in the year 1683 published his "Experiments and Observations touching Cold;" a work of great labour and ingenuity [77].

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[73] The windows in Russia are frequently covered with frost, and it is a common practice to clean them with salt. By rubbing the glass with a sponge dipped in common salt, the ice quickly dissolves, and the glass becomes immediately transparent.

[74] Mr. Boyle so early as the year 1683 noticed that no salt mixed with snow would produce ice, "unless it helps the snow to dissolve faster than else it would." *History of Cold*, title i. § 13.

[77] He describes how snow may be made artificially; he also

By these researches he discovered that either common salt, alum, vitriol, sal ammoniac, lump-sugar, oil of vitriol, nitrous acid, caustic ammonia, or alcohol, when mixed with snow, had the power of freezing water, and thus laid the foundation for the modern discoveries respecting frigorific mixtures [78].

About this time the use of a mixture of snow [79] and common salt had become very common in several countries in Europe. It was by a mixture of this sort that Fahrenheit, in the year 1710, fixed the zero of his thermometer, supposing this was the *extreme* point of cold, but a long period intervened before any facts of importance were added to those which Mr. Boyle had published on this subject.

The art of making ice was for many years practised only as an amusement, and no one suspected that it would ever be applied to such important purposes, both of science and luxury. Like gunpowder, and many other valuable discoveries, it was at first considered to be of very trifling consequence [80].

Some modern demonstrators in anatomy have

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speaks of a useful syphon which may be made with ice. *Additional Experiments*, pages 14 and 16.

[78] *Experimental History of Cold*, title i. pages 46—50.

[79] There is an account of some curious experiments by the Duke of Tuscany, in a work entitled *De Nive*, by Bartholinus.

[80] Beckman, vol. iii. page 373.

[81] Boyle's *History of Cold*. Postscript, page 253.

[82] Very easy and simple directions for making ice-cups for drinking of wine in summer, will be found in Mr. Boyle's *History of Cold*, title xiv. page 137.

availed themselves, of the use of frigorific mixtures in the dissection of the brain and the eyes of animals. To the great Boyle they are probably indebted for the idea; for in his History of Cold he says, "Many years since, I made an experiment of freezing the eyes of oxen and other animals, whereby the fluid humours of that admirable organ may be so hardened, as to become tractable, even to unskilful dissectors. So I did with the brains of animals, which, though too soft to be easily dissected, may by congelation be made very manageable[81].

In the beginning of the seventeenth century, drinking cups made of ice[82], and iced fruits were brought to table; and before its conclusion the French began to congeal all kinds of well-tasted juices, which were served up as refreshments at the tables of the great and wealthy[83].

In the year 1621 Barclay's Argenis, an interesting romance, was published at Paris[84], and its author places on the table of Juba, in the middle of summer, fresh apples for Arsidas, one half of which were incrusted with transparent ice. A bason of ice[85] filled with wine was also handed to

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[83] Beckman, vol. iii. page 373.

[84] The *Argenis* has gone through many editions, and has been translated into most of the European languages. The first edition has an excellent portrait of the author, with this singular inscription by Hugo Grotius:

"Gente Caledonius, Gallus Natalibus, hic est
Romam Romano qui docet ore loqui."

[85] How this bason of ice was made, the author has informed us. "Two cups," says he, "made of copper were placed the

him, and he was informed that to prepare all these things in summer was a new art[86].

A few years after the publication of the book just mentioned, a new beverage was introduced, called *lemonade*, which soon came into high repute, and was recommended by physicians against putrid diseases. About the year 1660 an Italian from Florence, having learnt a process of freezing confectionary, which had been before employed only by jugglers, conceived the happy idea of converting such beverage entirely into ice. This found a ready sale, and was the occasion of so great an increase in the number of sellers of lemonade, that in the year 1676 the *lemonadiers* of Paris were formed into a company, and received a patent from the Government[87].

In the beginning of the next century the process of congealing water by the mixture of salt or nitre with ice and snow was so well known[88], that it was then become, in Paris and elsewhere, a common amusement for children, who had a trick of placing a jug containing a mixture of snow and saltpetre on a table over which water had been poured, and agitating the mixture with a stick until the jug became firmly frozen to the table[89].

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one within the other, so as to leave a small space between them, which was filled with water: the cups were then put into a pail, amidst a mixture of snow and unpurified salt coarsely pounded, and the water, in three hours, was converted into a cup of solid ice, as well formed as if it had come from the hands of the pewterer."

[86] Barclay's *Argenis*, book v. chap. 5.

However, after the investigations of Boyle, no scientific experiments on the production of artificial cold seem to have been made till the subject attracted the attention of Dr. Blagden, Mr. Cavendish, Mr. Lowitz, and Mr. Richard Walker, who were at that time separately engaged in the same pursuit. The latter gentleman, however, was the first person who was able to produce ice in the middle of summer, merely by the solution of saline substances, without the aid either of ice or snow.

Having been thus successful, Mr. Walker pursued his experiments, and on the 20th of April 1787 actually succeeded in his attempt to freeze mercury. At the commencement of the experiment the temperature of the mercury was 45°; and as its freezing point is at 39° below zero, he obtained, without using a particle either of snow or ice, a reduction in temperature amounting to no less than 84 degrees.

This experiment, by which mercury was first seen in Great Britain in a state of solidity, was made at Oxford, Mr. Walker being at that time apothecary to the Radcliff Infirmary in that city.

The apparatus[90] which he used in this experi-

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[87] Beckman, vol. iii. page 377.

[88] The Duke de Chartres went often to a certain coffee-house in Paris to enjoy a glass of iced liquor. One day, in the year 1774, the landlord, we are told, to the great satisfaction and surprise of the Duke, presented him with his coat of arms formed of eatable ice.

[89] Beckman, vol. iii. page 373.

[90] A more simple and convenient apparatus for freezing mercury has been contrived by Dr. Henry. See his *Elements of*

ment consisted of four pans, progressively diminishing in size, placed one within another, and these, when thus arranged, were all placed in a vessel still larger. Some of the materials for producing the reduction of temperature were put in *each* of these pans, and others in bottles in the spaces between them, so that those in the outermost pan received, before being put together, the cold produced by the frigorific mixture in the larger vessel; and those in each of the inner ones received, in like manner, the progressively accumulated cold of the next exterior pan [91].

The materials which Mr. Walker employed were strong nitrous acid, sulphate of soda, and nitrate of ammonia. Other substances have also been employed for the same purpose, viz. muriatic and sulphuric acids, pure potash, nitrate of potash, muriate of ammonia, sulphate of soda, phosphate of soda, and various other salts.

It may be observed that the expense of making frigorific mixtures is trifling, because, in many cases, the salts may be recovered by evaporating the water in which they were dissolved. Mr. Walker, who was in the habit of recovering the salt, remarks that no diminution was observed in its effect, after many repeated evaporations.

But the cheapest and most efficacious salt which has been employed for the reduction of temperature

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Chemistry, plate iv. fig. 42. Another, on a different construction, by Mr. Pepys, may be seen in the *Phil. Mag.* vol. iii. p. 76.

[91] See Walker *On Artificial Cold.* 8vo. Oxford, 1796.

is the muriate of lime, which was first used by Mr. Lowitz; and this when mixt with snow is extremely active in the production of cold [92]. Five parts of this salt well dried, and in the state of crystals, with three parts of snow, sank the thermometer, in Mr. Walker's experiment, from 32° to −53°, which was a reduction of 85 degrees [93].

Mr. Lowitz directs, not only that the muriate of lime should be perfectly well dried, but that it should be in that state in which it is crystallized with the largest possible quantity of the water of crystallization, which is effected by putting the solution to cool when of the specific gravity of 1.50 or 1.53.

The different materials for producing cold may be mixed in a variety of ways; but as several circumstances should be attended to, according to the nature of the articles employed, in order to afford a favourable result, I must refer the reader to Mr. Walker's publication itself for proper instructions.

Dr. Beddoes has remarked that sulphate of soda, while it retains its water of crystallization, produces, on the addition of sulphuric acid diluted with an equal weight of water, 46 degrees of cold; but when it has fallen into powder by being deprived of its

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[92] It should be remembered that every frigorific mixture has a certain point of temperature beyond which it can never act in the production of cold, and this is the point at which the mixture itself becomes frozen.

[93] The greatest artificial cold which has yet been observed was −91°, which is 52° lower than the point at which mercury congeals, and 123° below the freezing point of water.

water of crystallization, it produces heat rather than cold; and yet that sal ammoniac and nitre, when well dried in a crucible, produce a greater degree of cold than if they had not received this treatment[96]. Where salts of any kind are employed, it is of consequence to have them fresh crystallized, thoroughly dried, and then finely pulverized. The mixtures should be made rapidly, and in vessels as thin as can be procured.

To this account of the various methods of producing ice by art, may be added a new mode of effecting the same purpose, which was invented by Dr. Wollaston.

It is well known that the temperature of liquids is cooled by evaporation, but in close vessels evaporation is limited by the great bulk into which the vapour expands. Dr. Wollaston, in a paper in the Philosophical Transactions, describes an ingenious contrivance of his, to which he has given the name of CRYOPHORUS, by means of which water may be frozen in close vessels by its evaporation, with great facility.

"The instrument which he employs is a glass tube, as shown in the Plate of Miscellaneous Articles, fig. 1. Its internal diameter is about one-eighth of an inch, each extremity is blown into a ball, and the tube is bent at right angles about half an inch from each ball. One of the balls is filled not quite half full of water. This liquid is boiled for some time to expel the air, and the capillary tube at the extremity

[96] Beddoes on Artificial Cold, in the *Phil. Trans.* for 1787.

of the other ball is then sealed hermetically. If the empty ball of this instrument be plunged into a mixture of snow and salt, the vapour within it is condensed so fast, that the water in the other ball freezes [95].

I cannot, however, close this part of my subject, without adverting to another philosophical expedient for the reduction of temperature, especially as it is one which has been productive of the most important and beneficial consequences. The discovery to which I refer is connected with the invention of the Miner's Safety Lamp, which has already been alluded to at the close of the first Essay, but which requires to be more particularly explained, now we are enumerating the various ways which have been resorted to for reducing the temperature of bodies by artificial means.

In the history of mining, nothing has perplexed the proprietors of our collieries, or annoyed the workmen, so much as the fire-damp; and yet many thousand men who had no other way of maintaining their families, were constantly obliged to submit to work in situations of the most imminent danger. It was usual for these poor men to creep with a lighted candle in their hands, inch by inch, as it were, along the galleries of a mine suspected to contain what they call foul air, in order to ascertain its presence, and guard themselves against its dreadful effects. But notwithstanding all their caution, explosions

[95] Thomson's *Annals of Philosophy*, vol. ii. p. 230.

frequently occurred, and the consequences were often of the most melancholy kind. The miners, with the horses and machinery, were sometimes thrown through the shaft into the air, and those individuals who might happen to escape the violence of the concussion, were often gradually suffocated in being obliged to breathe the carbonic acid gas and azotic gas which always remains in the mine after such explosions. Great numbers of men and boys are sometimes killed on such occasions; and not long ago no less than ninety-six persons who were working in the *Felling* colliery were, in an instant, destroyed by a similar accident.

These dreadful catastrophes kept the proprietors of our coal mines, and the families of the workmen, in a state of perpetual alarm, and little if any hope was entertained of an effectual remedy being discovered, until the subject engaged the attention of Sir Humphry Davy, who undertook to investigate the nature and chemical properties of the fire-damp, for the purpose of endeavouring to arrest its action, and prevent the ravages which it occasioned.

In the month of August 1815, Sir Humphry Davy first turned his attention to the subject, and knowing how desirable it was to find some substitute for the naked candles with which the men had been in the habit of working, he first tried Kunkel's, Canton's, and Baldwin's phosphorus, and likewise the electrical light in close glass vessels, but without success. He then constructed a lamp with two valves, so contrived that the valves closed whenever

the lamp was carried into an atmosphere contaminated with fire-damp; but it was found that this lamp could not be used in explosive atmospheres.

Having been disappointed in these attempts, he then undertook "a minute chemical examination of the substance with which he had to contend (the fire-damp), and these investigations led him to the discovery of the principles by which explosion and flame may be arrested and regulated; and by means of which the miner is not only able to subdue and controul, but likewise to render useful, his most dangerous enemy."

During these experiments, he found that the fire-damp is light-carburetted hydrogen, or hydrogen gas holding carbon in solution; that it will not explode unless mixed with a portion of atmospheric air; that it explodes with most vehemence when mixed with seven or eight times its volume of air; that it retains its explosive power when mixed in the proportions of only one of gas to fourteen of air; and that when the atmospheric air is in greater quantity, the light of a taper merely becomes enlarged when brought within it, and that this effect is perceptible in a mixture of even thirty parts of air to one of gas. He found also, that the fire-damp is much less combustible than other inflammable gases; that it is not exploded by red-hot charcoal or red-hot iron, though iron at a white heat will explode it; and that "on mixing one part of carbonic acid with seven parts of an explosive mixture of fire-

damp, or one part of azote with six parts, their powers of exploding were destroyed."

In the prosecution of these inquiries he found that it was difficult to explode the mixture of air and fire-damp in small tubes; and that in tubes of only one-seventh of an inch in diameter, and open to the atmosphere, it could not be inflamed, and especially if the tubes were metallic.

"In reasoning upon these various phenomena it occurred to him, as a *considerable* heat was required for the inflammation of the fire-damp, and as it produced, in burning, comparatively a *small degree* of heat, that the effect of carbonic acid and azote, and of the surfaces of small tubes in preventing its explosion, *depended upon their cooling powers*,—upon their lowering the temperature of the exploding mixture so much that it was no longer sufficient for its continuous inflammation."

"This idea led to an immediate result:—the possibility of constructing a lamp, in which the cooling powers of the azote and carbonic acid formed by combustion, or the cooling powers of the apertures through which the air entered or made its exit, should prevent the communication of explosion."

"I made," says Sir Humphry Davy, "several attempts to construct safety-lamps which should give light in all explosive mixtures of fire-damp; and after complicated combinations, I at length arrived at one evidently the most simple,—that of surrounding the light entirely by wire gauze, and making the

same tissue feed the flame with air and also emit light."

"In plunging a light," continues he, "surrounded by a cylinder of fine wire gauze into an explosive mixture, I saw the whole cylinder become quietly and gradually filled with flame; the upper part of it soon appeared red-hot, yet *no explosion* was produced."

"It was easy at once to see, that by increasing the cooling surface in the top, or in any other part of the lamp, the heat acquired by it might be diminished to any extent; and I immediately made a number of experiments to perfect this invention, which was evidently the one to be adopted, as it excluded the necessity of using glass or any fusible or brittle substance in the lamp, and not only deprived the fire-damp of its explosive powers, but rendered the inflammable gas itself an useful light."

Omitting the detail of other experiments, it was found that iron wire gauze, composed of wires from one-fortieth to one-sixtieth of an inch in diameter, and containing twenty-eight wires or seven hundred and eighty-four apertures to the inch, was safe under all circumstances; and this material Sir Humphry Davy was therefore induced to adopt for the construction of lamps for coal-mines.

In the month of January 1816, these lamps were introduced at some of the large mines in the North of England; and they have been in use, with some few alterations and improvements, ever since; the utmost confidence being now placed in them by the workmen themselves, as well as by their employers.

The circumstances which render this lamp an instrument of perfect safety may be thus stated: "Flame is gaseous matter heated so highly as to be luminous, and that to a degree of temperature beyond the white heat of metals or other solid bodies. When an attempt is made to pass flame through a very fine mesh of wire gauze, the gauze cools each portion of the elastic matter that passes through it, so as to reduce its temperature below that degree at which it is luminous; and the diminution of its temperature is proportional to the smallness of the mesh, and the mass of the metallic wire." Moreover, the fine wire gauze is not only a conductor but a radiator of heat; consequently it possesses great cooling power; and when by this, or any other means, we cool a body of flame, the effect of cooling it will most certainly be to extinguish it. The wire gauze which encircles the lamp does not prevent the passage of the inflammable gas, but it prevents its emission *in a state of inflammation*; consequently nothing can pass from the interior of a lantern properly constructed, that is, at a temperature sufficiently high to inflame the explosive atmosphere of the mine. The temperature of a metallic body, even when *white-hot*, is far below that of flame; therefore, when the wire gauze of the lantern is red-hot, it will abstract heat enough from the flame of the fire-damp to extinguish it before it passes through the meshes. So, if a wire gauze sieve be held over the flame of a common lamp, it will prevent the flame from pass-

ing it, although the heated air which passes through will be hot enough to char a piece of paper held above the sieve; a phenomenon which is precisely similar to that exhibited by the wire gauze cylinder. A very simple experiment for the further illustration of the effect thus produced, has been suggested by Sir Humphry Davy. "Let," says he, "the smallest possible flame be made by a single thread of cotton immersed in oil, and burning immediately upon the surface of the oil: it will be found to be about one thirtieth of an inch in diameter. Let a fine iron wire of the one hundred and eightieth of an inch be made into a circle of one-tenth of an inch in diameter, and brought over the flame. Though at such a distance, if it be cold, it will instantly extinguish the flame: but if it be held above the flame, so as to be slightly heated, the flame may then be passed through it. That the effect depends entirely upon the power of the metal to abstract the heat of the flame, is shown by bringing a glass capillary ring of the *same* diameter and size over the flame: this being a much worse conductor of heat, will not extinguish it even when cold."

To pursue the history of the discovery and improvement of the safety-lamp, it must be observed, that twelve months after its first adoption by the miners, viz. in January 1817, an important practical addition was made to it, founded entirely upon a new principle. Sir Humphry Davy having been told that the perfect safety which attended the use of his lamp, often induced the men to go into more

explosive atmospheres than they otherwise would, and that this sometimes occasioned the lights to be extinguished, the genius of our philosopher enabled him, by means of the metal called platinum, to obviate the inconvenience in the most complete manner possible. Knowing that platinum has a small capacity for, and is a very slow conductor of heat, in which respects it is not at all analogous to any of the other metals except palladium, it occurred to him, that upon those properties of this metal he might found the improvement he was in search of. Pursuing this idea, he contrived to suspend a coil, or little cage of small platinum wire, from one-sixtieth to one-seventieth of an inch in thickness, over the flame of each lamp; the effect of which is, that the moment the light is extinguished by an increased quantity of fire-damp in the atmosphere, the coil of platinum wire becomes of an intense red heat; and this affords light enough to enable the men to find their way through the different passages to the entrance of the mine. This alone would have been an important improvement on the original safety lamp:—but this is not all; for no sooner has the workman arrived at a part of the mine in which the atmosphere is in a state of greater purity, or where it contains less than one-fourth in volume of carburetted hydrogen gas, than the heated platinum wire of itself re-lights the lamp, and the men are enabled to return to their work without interruption, and in perfect safety.

There is another advantage attendant on the use

of the platinum, viz. that the red-hot coil of platinum wire consumes the fire-damp within the lantern, and this without flame; yielding only a beautiful light by the ignition of the charcoal, which is one of its component parts. It is also to be observed, that a candle will burn in one of these lanterns made safe with metallic gauze, as well as in the open air; and that, whenever the fire-damp is so mixed with the external atmosphere, as to render it explosive, the light in the safe lantern will be extinguished, and warning will thus be given to the miners to withdraw from, and to ventilate that part of the mine. Another important circumstance connected with the use of the safety-lamp is, that the men can never be in any danger with respect to respiration, so long as the platinum continues ignited; for even this phenomenon ceases when the foul air forms about two-fifths of the volume of the atmosphere; and before this, it may be breathed without injury.

The action of the platinum wire has been thus described by Sir Humphry Davy himself: "I introduced (says he) into a wire gauze safe-lamp a small cage made of fine wire of platinum of the one-seventieth of an inch in thickness, and fixed it by means of a thick wire of platinum about two inches above the wick which was lighted. I placed the whole apparatus in a large receiver, in which, by means of a gas-holder, the air could be contaminated to any extent with coal gas. As soon as there was a slight admixture of coal gas, the pla-

tinum became ignited; the ignition continued to increase till the flame of the wick was extinguished, and till the whole cylinder became filled with flame; it then diminished. When the quantity of coal gas was increased so as to extinguish the flame, at the moment of the extinction the cage of platinum became white-hot and presented a most brilliant light. By increasing the quantity of the coal gas still further, the ignition of the platinum became less vivid. When its light was barely sensible, small quantities of air were admitted, its heat speedily increased; and by regulating the admission of coal gas and air, it again became white-hot, and soon after lighted the flame in the cylinder, which, as usual, by the addition of more atmospherical air, re-kindled the flame of the wick."

It is also remarkable that the fire-damp and the oxygen of the atmosphere will combine, when in contact with the hot wire, *without flame*; and yet produce heat enough to preserve the wire ignited, and to keep up their own combustion; and this will go on until the inflammability of the mixture is entirely destroyed. A temperature much below ignition is sufficient for producing this curious phenomenon; and if the wire be taken out of the lantern and cooled in the atmosphere till it ceases to be visibly red, when it is replaced it will again instantly become red-hot.

At first the miners were very apprehensive respecting the durability of the wire gauze; but time has increased the confidence of these men in the

apparatus, which has now been in use for five or six years in the most dangerous mines in Britain, and exposed to all circumstances which the variety of explosive mixtures can occasion. And the idea of the wire gauze burning out, is shown to be unfounded; for the carbonaceous matter produced from the decomposition of the oil, tends not only to prevent the oxidation of the metal, but likewise revives any oxide already formed; and this coaly matter, when the fire-damp is burning in the lamp, chokes the upper apertures of the cylinder, and gradually diminishes the heat by diminishing the quantity of the gas consumed. "I have seen," says Sir H. Davy, "wire gauze lamps in the hands of workmen, which they had used for several months, and which had been often red-hot in explosive atmospheres, and which were still perfect."

It appears moreover from Mr. Buddle's report, that the brass collar of the wire gauze cylinders is secured to the bottoms of the lamps by locks, which can only be opened by the lamp-keeper; so that the workmen cannot either by accident or carelessness expose themselves to danger by separating the wire gauze cylinders from the bottoms of the lamps.

After finishing their day's work, the colliers bring their *Davys* (as they call them) to the lamp-keeper's cabin, who, unlocking them, takes the bottoms into his own possession and allows the colliers to take the wire gauze cylinders home for the purpose of cleaning them thoroughly. When the colliers return to their work the following morning,

the lamp-keeper having replenished the lamps with oil and cotton, lights them and screws on their tops, and then examines them with the utmost care, before he delivers them for use; but if the least injury or defect appears in the gauze, or in any other part of a lamp, it is immediately set aside to be repaired, and the person to whom it belongs is supplied with a perfect one.

The gentleman to whom the public is indebted for the above account concludes another of his reports in the following manner: "It is not necessary," says he, "that I should enlarge upon the national advantages which must result from an invention calculated to prolong our supply of mineral coal, because I think they will be obvious to every reflecting mind; but I cannot conclude without expressing my highest sentiments of admiration for those talents which have developed the properties and controlled the power of one of the most dangerous elements which human enterprize has hitherto had to encounter."

As some persons, who have no means of conversing with the workmen in mining districts, or of witnessing the action of the lamp in a coal mine, may be gratified in making the experiment for themselves, I shall relate a very simple mode by which the same effect may be produced, though in a different way, viz. By throwing a little ether into the bottom of a glass or stone jar, the vapour arising from the ether mixing with the air, will produce what is really an explosive atmosphere, and this,

when the lighted lamp is immersed in it, will burn within the wire gauze in a manner exactly similar to the real fire-damp, without inflaming the ether in the bottom of the jar.

Thus have I given the best account I am able of the discoveries that led to the invention of the Safety Lamp; which appears to me to be the most valuable and important instrument that science has presented to the arts since the discovery of the steam engine.

I have made great use of Sir Humphry Davy's own account of the progress of his discovery; and often in his own language[96]; and I conceive I cannot sum up the whole better than by quoting the paragraph with which he has closed the publication alluded to. "Whatever," says he, "may be the fate of the speculative part of this inquiry, I have no anxiety as to the practical results, or as to the unimpassioned and permanent judgement of the public on the manner in which they have been developed and communicated; and no fear that an invention for the preservation of human life and the diminution of human misery will be neglected or forgotten by posterity. When the duties of men coincide with their interests, they are usually performed with alacrity; the progress of civilization ensures the existence of all real improvements; and however high the gratification of possessing the

[96] See an octavo volume entitled *"On the Safety Lamp for Coal Miners; with some Researches on Flame.* By Sir Humphry Davy." London, 1818.

good opinion of society, there is a still more exalted pleasure in the consciousness of having laboured to be useful."

I hope it will not be thought that this detailed account of the invention of the Safety Lamp is misplaced; I had no idea it would have extended to such a length: but when it is considered that this part of my essay was expressly designed to be employed in "treating of the various expedients for increasing and diminishing temperature," I trust it will be perceived that it was impossible I could lightly pass over a discovery of such momentous interest and importance.

Having offered these remarks on a variety of expedients for the modification of heat, a few observations on some of the means of guarding against and MODIFYING the effects of COLD, may not be unacceptable to the reader.

Nature has made choice of several expedients for lessening the power of cold, and moderating the rigour of severe winters. The snow which generally covers the earth at this season is one of these, and it is very efficacious in preserving the earth at one uniform temperature, however cold may be the surrounding atmosphere. In like manner the atmosphere itself, being a bad conductor of heat, is a great preserver of the earth's temperature. Were it not for the atmosphere, the caloric inherent in the globe would soon pass off and be dissipated in unbounded space.

The temperature of the human body is uniformly preserved in the same manner. The air which is infolded within our garments prevents the animal heat from passing off, and hence it is that loose clothing is generally warmer than that which is fitted closer to the body.

There seems to be a living principle in vegetables, in the seeds of vegetables, and in fish, which enables them to resist the effects of cold, and prevents their freezing in temperatures lower than that at which water congeals. For in rivers and other great bodies of water, when the water freezes, the rapidity of the process is moderated by the water itself giving out a large portion of caloric, during the act of freezing. This circumstance is, in a variety of instances, of incalculable benefit to the world, besides shortening the duration of winter, and lessening its severity.

Dr. Black has an experiment which decisively proves this to be a fact. "If," says he, "when the air is at 22° we expose to it a quantity of water in a tall glass, with a thermometer in it, and covered, the water will gradually cool down to 22° without freezing. Things being in this situation, if the water be shaken, part of it instantly freezes, and the temperature of the whole rises to the freezing point, so that the water acquires 10° of caloric in an instant.

Man, in different parts of the world, has availed himself of some of these principles, and applied them artificially, either to better his situation with

respect to climate, or to aid him in the common operations of life.

Thus, during the winter at Hudson's Bay, the surface of the lakes and rivers is covered with ice of such great thickness, that no water can be procured without cutting through the ice with axes and wedges, which is a very laborious and tedious operation. As soon, therefore, as the surface of the water which has been laid open has acquired a thin plate of ice, the labourer heaps over it a quantity of snow, which, by being a bad conductor of heat, prevents the caloric of the water from passing upwards according to its natural tendency. It is by this expedient[97], that during the remainder of the winter, the inhabitants have only to remove a little of the snow, when occasion may require it, and they have water immediately.

A traveller of undoubted credit informs me, that the birds killed by the shooting parties during the winter in Hudson's Bay, would be soon frozen if they were carried as is usual with sportsmen in England whilst in quest of a further supply, and that this would occasion much difficulty in removing the feathers. It is, therefore, usual to adopt the following expedient: a hole is made in the

[97] In Tibet a different expedient is adopted. "It is the practice of the husbandmen," says Mr. Turner, "to cover the low lands in the vallies with water, immediately on the approach of winter, which incases their surface with a sheet of ice, and prevents their being stripped of the soil by the violent winds." Turner's *Embassy to Tibet*, 4to, London, 1806, page 354.

snow, and in this the birds are deposited with snow thrown over them, by which means their warmth is preserved till the party return.

In some northern regions, where there are fortified places surrounded by moats, the inhabitants have staved casks of fish oil into the intrenchments, when they have been afraid of the approach of an enemy, that the oil, thus interposed between the surface of the water and the atmosphere, and being incongealable by cold, might protect the subjacent water from freezing, and keep the moats impassable [98].

The circumstance of an undisturbed body of atmospheric air defending whatever may be inclosed within it from the accession either of heat or cold, has, of late years, been taken advantage of in a variety of instances. Hence the origin of double doors and double windows, which infold sheets of air between them, and thus preserve the apartments at one uniform temperature. For, as atmospheric air is a bad conductor of heat, the doors and windows guarded in this way neither admit the heats of summer nor the cold of winter, while at the same time they prevent the escape of that genial warmth which it is so desirable to preserve in the apartments of the sick and the aged at all seasons.

In like manner certain culinary utensils are fitted up with double covers of block tin or copper, and

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[98] Olaus Magnus in *Historia Gentium Septentrionalium*, lib. xi. cap. 20, 21.

in such utensils any fluid will boil sooner than it would in others, and will also be preserved at any particular temperature by the consumption of less fuel than would be required if they were covered only with single covers [99]. By similar contrivances the apparatus in some manufactories is sooner heated and more easily preserved at one and the same temperament.

A modern philosopher has shown, by direct experiment, the effect of a sheet of air in keeping metallic or other pipes warm which are designed to convey heat; and at the same time has explained how, by a like expedient, liquids might be preserved in a cool state in hot climates.

"A cylinder-canister," says he, "of planished tin, two inches in diameter, and of equal height, filled with boiling water, took 117′ to cool from 30° to 10°; but inclosed within a similar canister of four inches in diameter, it required 176′ to make the same descent. Another cylindrical canister of four inches, and which took 156′ to cool from 20° to 10°, required 356′ when cased with a similar one of five inches [100]."

I have no doubt but that ice might be transported from place to place in the midst of summer, and preserved for any length of time, if the vessel containing it were, agreeably to Mr. Leslie's proposal, placed within the innermost of a number of tin ca-

[99] There are several very decisive experiments on the advantages of double covers, in Rumford's *Essays*, vol. ii. p. 17, &c.

[100] Leslie *On Heat*, 8vo, London 1804, page 380.

nisters, which fit one within the other, especially if the outward one were clean and polished.

On the same principle Mr. Buchanan has recommended the protecting water-pipes from freezing, by inclosing them in tin-plate tubes, leaving a space of about an inch all round the leaden pipes [101].

There is a great difference in various substances, in their power of conducting caloric, and this is shown in a remarkable manner in the manufacture of glass; for when the materials are formed into the state of perfect glass, if the manager of the fire neglect to keep the grate completely covered with coals, a stream of cold air will rise through the bars and strike upon one or more of the crucibles, which it will split or *crever*, as the workmen call it, from the top to the bottom. But if the materials be not entirely fused, so as to be converted into perfect glass, then this effect will not happen. This is a fact well known to glass-makers, and has always been deemed inexplicable. May it not however be thus explained? The materials of which glass is made have the power of conducting caloric with rapidity; consequently, when the outside of the crucible is suddenly cooled, the caloric from its inner surface can escape among the materials, and allow of its cooling in a degree equal to the cooling of the outside: on the contrary, when the glass is fully formed, it is so bad a conductor of heat that it cannot carry off that which is superabundant; therefore the crack of the crucible is the inevitable consequence.

[101] Buchanan *On the Economy of Heat*, 8vo, page 128.

Metals are the best conductors of heat, and hence it is that the pipes which are employed to convey heated air or steam for warming apartments, should always be metallic; and when it is desirable that the heat should be given off rapidly, these pipes should be rough, or otherwise covered with a coat of paint.

In some distilleries there is a considerable length of metallic pipes between the still-head and the worm-tub or refrigeratory: all such pipes should be painted black.

On the contrary, whenever it is an object that such pipes should preserve the heat[102] as long as possible, as is always the case when metallic pipes are employed to convey heated air, hot water, or steam to a distance, the pipes should be conveyed under ground or otherwise highly polished, and always kept perfectly clean. A silver tea-pot on the same principle preserves the tea hotter than most others, and consequently extracts the vegetable principle more effectually. For the same reason, our planished tin covers will preserve the warmth of our provisions exactly in proportion to the height of their polish and the degree of cleanliness with which they are kept.

In some of the print-works in Lancashire, boiling water is conveyed by copper pipes under ground from the steam-engine boiler to the different work-

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[102] For an account of the different power which bodies with different surfaces have of preserving heat, see Leslie *On Heat*, p. 78, &c.

shops, for the uses of the workmen; and in some cases the heat is so well preserved, that the water is delivered in the various apartments only two or three degrees below the boiling point.

With respect to the ECONOMY of FUEL, which naturally forms a branch of this essay, so much has been professedly written upon the subject by Count Rumford, that there seems nothing of importance left for others to add. I shall therefore presume to offer very little to his observations, except a few hints which arise out of my own practice in the conduct of the manufactory in which I am personally engaged.

It is impossible, in an economical point of view, to give any general directions for the choice of coal, since this depends so much on the different localities and other circumstances; a description of the several varieties will be found in the Essay on Carbon. It may, however, be observed, that in manufactories where large and expensive iron boilers are employed, sulphurous coals should be avoided, as the sulphur which rises during combustion is apt to occasion a rapid decay of that part of the boiler which is exposed to the action of the fire. It produces a sulphuret of iron, which wastes away as fast as it is formed. This is more particularly the case with those cast-iron stills which are required to be red-hot, such as the pots in which the makers of prussian blue flux a mixture of animal hoofs and horns with a caustic fixed alkali.

The following table of the comparative heat of different kinds of fuel was drawn up by Mons. Lavoisier. Equal quantities of heat were produced by the combustion of the following quantities of the combustibles annexed.

	Pounds.	Measure.
Cokes . . .	403	17
Pitcoal . . .	600	10
Charcoal . .	600	40
Oak wood . .	1089	33

In this experiment the cokes required 12½ hours for their combustion, the coal 20 hours, the charcoal 5, the oak 4—4. An estimate has also been made of the relative quantities of heat produced from similar materials by Count Rumford, but I must refer the reader to his work for particulars[103].

M. Wiegleb has stated it as his opinion, that in the choice of wood-fuel, the beech and hornbeam are to be preferred; next the oak, and then any other woods of great solidity. Next to these, the alder, aspen, birch, fir, ash, and the lime. The former excite a greater heat, and burn longer; the latter exhibit more flame, and leave but little residuum.

Loysel has shown that it is improvident to burn different species of wood together, and that it is

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[103] Rumford's *Essays*, vol. ii. pages 75, &c., also pages 134—137.

[104] *Essai sur l'Art de la Verrerie*, page 67.

absolutely important in many operations to sort the wood, and never to use more than one kind at a time in those works which require a lively clear fire and a pure flame [104].

Charcoal is fitter for small chemical operations, as it is more easily managed: that which is made of the more solid woods is to be preferred.

Refuse tan, made up into cakes, is also very fit for firing, where a gentle and continued heat is advantageous.

In some places turf is used with advantage. Formerly it was much employed in some of our West Indian islands; but since hands have been scarce in consequence of the discontinuance of the slave trade, the planters cannot spare any of their men to cast turf, and are now obliged to take pitcoal from England. There is a great difference, however, in its internal quality: the heavy bituminous kind called *peat* [105] is the best; but some care is required in drying it properly to prevent its entering into spontaneous combustion.

Mr. Mushet, of the Clyde iron works, gives the following calculation of the expense of getting peat in Scotland. A man, he says, will with ease cast 4,000 of an ordinary size in a day. For this quantity are required two carriers, and one person to pile

[105] This article has for ages been used as fuel by the people of the north of Europe; but the learned Torfeus says that its use was first made known to the inhabitants of the Orkney and Shetland islands, by one Einar, a Norwegian, who from that circumstance was named Torf Einar. Jameson's *Mineralogy of the Scottish Isles*, quarto, 1800, vol. ii. page 121.

it to dry. The peat when thoroughly dried will weigh nine pounds each; the product, therefore, will be 12,000 pounds, or upwards of five tons. The expense of this is as under:

	s.	*d.*
Man's wages, 1 day,	2	6
Two women, at 1*s.* do.	2	0
Girl to pile it,	0	6
	5	0

or 1*s.* per ton.

It has been found that four tons of dried peat will make something more than one ton of peat-char, which will produce a much stronger fire than coals or cokes [106].

Dr. Plot, after describing the method of cutting turf in Staffordshire, says, "the large ones in good weather will dry on one side in eight, on the other in four or five days at most. When dried, if they intend them for fuel in winter, they pile them up round in the manner of a hay-rick, ten or twelve feet high, and let them stand all summer; but if they are designed for manuring their land, they heap them up a good quantity together on the ground and set fire to them, which they will take of themselves if they are dry [107]."

A very economical kind of fuel is charred turf, but it has a very disagreeable smell during its com-

[106] *Philosophical Magazine*, vol. vii. page 44.
[107] Plot's *Staffordshire*, chap. iii. § 14.

bustion, which is an objection to its use in open fire-places, and there is some nicety required in managing the process of preparing it, which I believe nothing but practice can teach. M. Sage, who has published a paper on this subject in the Memoirs of the Academy of Sciences at Paris, entitled "An Inquiry into the comparative Intensity of the Heat produced by the Combustion of Charcoal and charred Turf," asserts that the heat produced from the latter is nearly in the proportion of three to one[108].

M. Goettling has described how hydrogen gas may be collected from certain vegetables, and employed for the production of heat, in small chemical operations, instead of sperm oil or alcohol[109]; but all such combustible agents are too dear for common practice.

The management is, however, generally of greater consequence than the choice of fuel. The kind of fuel which is most suitable for any particular operation, is soon discovered, but how to employ it so as to produce the greatest quantum of heat by its means is not quite so obvious.

Count Rumford has stated that, in general, not less than seven-eighths of the heat generated, or which with proper management might be generated, from the fuel actually consumed, is carried up into the atmosphere with the smoke, and totally lost.

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[108] An abstract of this paper may be seen in *The Repertory of Arts*, vol. v. page 419.

[109] *Almanack for Chemists*, for the year 1785, page 185.

How important then is it that every proprietor of a manufactory should investigate the causes of this loss, and endeavour to remove them!

In the year 1686 Dalesmius contrived a furnace at Paris on a very simple construction, for economizing fuel by burning the smoke. Since that period we have had many contrivances for the same purpose, possessing different degrees of merit, and an account of most of them may be seen in the periodical journals of the day. I believe, however, that none of them equal the patent invention of the Messrs. Parkes of Warwick[110].

Where boilers are set in brick-work over closed fire-places, the most common defect is that of having the fire-places too large. This often arises from the obstinacy of an unskilful bricklayer. It is a great want of economy to employ inferior workmen to erect any kind of fire-work. Whatever may be the expense, I have always found an advantage in having furnaces well built in the first instance. The consequence of having the fire-place too large is, that the bars cannot be entirely covered with fuel, and the cold air rushing from the ash-pit, between the uncovered bars, actually counteracts the effect of a great part of the burning fuel. In setting stills or boilers, it should be a general rule to have the fire-places no larger than is absolutely necessary for

[110] See *The Journal of Science, Literature, and the Arts*, No. 25, page 58. A particular description of the invention of Dalesmius will be found in the *Journal des Savans*, for 1686, page 116.

containing as much fuel as will be required to produce the intended purpose.

The fire-place should not only be small, but it should be constructed so that the whole of the bottom of the boiler be exposed to the action of the burning fuel. This is very effectually accomplished in some steam-engine boilers. These are of an oblong form, and they have a flue of from eighteen to thirty inches diameter running from end to end through the middle of them. The fire therefore first plays against the bottom of the boiler, and then passes through the midst of the water before it reaches the chimney. Might not this principle be applied in various other ways with advantage? It is important that the whole of the flame and heated air do actually impinge upon the bottom before they reach the sides to pass from them to the chimney; for the heat which is applied at the bottom of a boiler will be infinitely more effective than the same portion of heat when applied to its sides. It is on this account that some large stills and other vessels of copper are made with the bottom to project inwards, presenting a concave instead of a convex surface to the action of the fire.

These considerations explain why there is so great a waste of fuel whenever pots or other vessels are heated over an open fire-place; for in this case, the heat only skims over the bottom, and passes off immediately into the surrounding atmosphere.

The doors of closed fire-places also are generally as improper as the fire-places themselves. They are

usually made extremely thin, and the frames very light; which not only occasions them soon to wear out, but is the cause of their warping and twisting, and consequently they never shut close afterwards. These doors are likewise made to fall into a rabbet, and are fitted up with latches, both of which are inconvenient, and indeed useless.

Having had many years experience in fitting up furnaces, I am decidedly of opinion that where cast-iron doors are employed, an opening of ten inches should have a door not less than three quarters of an inch thick; and larger fire-places should have thicker doors in proportion. These should be fitted up with strong wrought-iron hinges, such as will allow the doors to fall flat against the frames; and instead of moveable latches, each door should have a large projecting knob firmly riveted into it.

I have found it advantageous to have the straps of the hinges thick, and of such a length as to extend entirely across the door; for when these are well riveted to the door, they prevent the latter from warping, however intense may be the fire.

The cast-iron frames ought to be as thick at least as the doors; and they should be two or three inches broad, to enable them to stand steadily against the walls of the furnace. In setting the frames, they should be fixed inclining a little towards the fire-place: this gives the doors a tendency to keep shut, and renders latches useless. Bars of wrought-iron, well fastened, should also go, one from each corner, in a spreading direction, not less than eighteen

inches or two feet into the solid mass of brick-work on which the boiler is to stand.

There is a benefit arising from having these straps long and substantial, which may not at first be apparent. They prevent the frame from receding from the brick-work, the consequence of which would be that air would pass into the fire-place between the frame and the masonry, and thus impair the draught of the furnace.

It is also of importance in every close fire-place, to have a door to the ash-pit; one that shuts easily and fits close to the frame on which it hangs; for without this it is impossible ever to regulate a fire so as to reap every advantage from its effects.

Having experienced the benefit of ash-pit doors, I have for several years been in the practice of having my fire-places fitted up with double doors and frames; that is, I have a strong iron frame cast, with two openings; to one a door is hung for the fire-place, and to the lower opening I adapt another for the ash-pit. The peculiar advantage of this is, that a double frame of this sort is more easily fixed, and can be attached more firmly to the brick-work, than it would be possible to fix two frames, one immediately above the other.

These doors and frames are expensive at first, because they are weighty[111]; but in the end they will be

[111] One of these double frames, in which the fire door is ten inches by eleven inches, and the ash-pit door eleven inches by sixteen inches, with the doors properly hung with strong wrought-iron hinges, costs at the first hand about 40*s*.

found to be more economical than any ready-made sale-doors that can be found.

Besides, since I have had these doors to the ash-pits I have dispensed with the registers in the chimneys; for, I find that by a proper attention to the opening and shutting of the ash-pit door, I can admit any portion of atmospheric air into the fire-place, and thus have a complete command of the temperature and its application.

For some time I had registers in the chimneys, as well as doors to the ash-pits; but finding that both were more than servants would attend to, I have now discarded the former altogether, and perceive that every effect that can be desired may be produced by the ash-pit doors alone.

However deep the ash-pits may be, it is always advisable to have doors to them. Some scientific men in the metropolis have had doors of three feet in height to the ash-pits of their brewing coppers, and have found them very economical.

I have sometimes had moveable registers in the centre of the ash-pit doors; but these are too troublesome to be managed by ordinary servants; and a common plain ash-pit door, when properly hung, may be readily opened an inch, two inches or more, or entirely shut, according to the choice of the laboratory-man employed.

In reverberatory furnaces for the decomposition of neutral salts and the manufacture of alkalies, ash-pit doors are of no use, as it is never necessary to check the fire suddenly, as in other operations.

On the contrary, I have found it advantageous to have the ash-pits as deep and the chimneys as high as possible, in order to occasion a strong and uninterrupted draught.

No chimney should be less than thirty feet high; and for large fire-places, or where more than one flue goes into a chimney, it ought to be much higher, and larger in proportion.

In the Isle of Dogs, near London, there are chimneys for steam-engine boilers and for iron furnaces 100 feet high, which are found to be very advantageous. At Paddington water-works the chimney is 120 feet from the plinth to the summit.

I cannot suffer this opportunity to pass without remarking that the proprietors of reverberatory furnaces should contrive to continue their processes night and day; or, if that be impracticable, they should rake up the fire and stop the passage to the chimney so as to prevent the furnace from cooling during the night. Furnaces thus worked will last six or seven times as long as those do which frequently stand idle. The contraction of the materials during the time of cooling, and the subsequent expansion, wear them out rapidly.

Where the heat is so intense as it is in these furnaces, doors and frames of the common make, or such as have been just described, would be quite improper, and even wasteful, for they would be constantly red-hot: hence they would not only soon wear away, but being in this state of incandescence

they would carry off a large portion of the heat, which ought to be employed in reducing the materials within the furnace.

For large reverberatory furnaces, steam-engine boilers, and other great concerns, I have sometimes seen very wide wrought-iron doors lined on the inside with a plate of cast-iron well riveted to the door. By forming these hollow, that is, if they were put together so as inclose a thick sheet of atmospheric air, the door would become a non-conductor of heat, and would be very suitable for such apparatus.

Having experienced the inconvenience of common doors and frames, I had recourse to a contrivance of hanging a thin sheet of wrought-iron before the fire-place, which proved to be a great amendment; and after this I had a door made with fire-bricks, the joints of which were secured with loam, and held in their places by four flat plates of iron screwed together at the corners. This massy door was moved upwards or let down before the fire-place by means of a weight which exactly balanced it, and was attached to a chain passing over a pulley.

This was an improvement upon the former; but both had their inconveniences, and these inconveniences led to the adoption of a small iron hopper fixed horizontally in the brick-work, properly let into the wall to defend it from the fire, and stopped by a thick piece of iron, cast exactly to fit it [112].

[112] See the plate of miscellaneous articles, fig. 2 and fig. 3.

This I found to be a most complete way of closing a fire-place, as no air can possibly get admittance but through the ash-pit, this being the only way by which it ought ever to pass. I made use of this kind of hopper twenty years ago, and have never seen any reason to alter my opinion of them. I was indebted to a work of Mr. Dossie, "The Elaboratory laid open," for the idea.

There is, however, an inconvenience attending these square stoppers of iron, viz. If the wall of the fire-place be not very thick, and the hopper fixed at the very outside of the brick-work; whenever the fire becomes intense, the stopper is apt to expand by the heat, and get so firmly fixed within the hopper as sometimes to be attended with much trouble. I have, however, occasionally employed these kind of hoppers for closed fire-places of the very smallest size, and have then been much satisfied with them. In such cases the heat not being so intense, this inconvenience does not happen.

Reflecting on the objection just referred to, it occurred to me that a hopper might be so fixed as to be stopped with small coal instead of the usual door, and that in this way the difficulty might be avoided. I therefore made such an alteration in the construction of the last reverberatory furnace which I had occasion to erect, as enabled me entirely to discard the use of any metallic door or stopper whatever.

In this furnace the hopper which I employed was five inches square in the clear, and this was fixed

upon a broad plate of iron built in the brick-work, and projecting eight inches beyond the face of the wall. The design of this was merely to be a support for the small coal which was to fill the hopper, and be piled against it, as a succedaneum for the iron stopper above mentioned.

The small of pit-coal, being a non-conductor of heat, proved to be a mode of stopping the entrance of a furnace as perfect as probably will ever be devised: for, if a furnace draw well, the coal which fills the hopper will not become ignited at all, except that part of it which is nearest the burning fuel; and when the hopper is properly stopped, one cannot discover how any of the heat of the furnace can possibly escape by means of the door-way.

When it becomes necessary to replenish the fire, all that the workman has to do, is to loosen the coal within the hopper, to push the whole of it into the fire-place with a shovel which should be made on purpose to fit it, then to throw in as much fresh fuel as he judges to be sufficient, and again to stop up with small coal as before. It must be observed, that the hopper should be fixed several inches above the level of the fire-bars, that whatever fuel is put through may fall into the fire-place without any difficulty.

It should be recollected, however, that whatever perfection there may be in the mode of stopping the entrance into a furnace, this will be no cure for a large fire-place; for if a fire-place be larger than it ought to be, or so constructed that the hopper

does not command every part of it, a continual current of cold atmospheric air will rush in between those bars which are not covered with fuel, and carry much of that heat into the channel of the chimney which ought to be spent within the furnace.

This is the chief circumstance which renders a hopper fire-place so much better than those with a door and frame; for where there is a hopper there can be no occasion for any door and frame; and the *four* sides of the furnace may be built exactly alike and all brought up sloping with masonry. Such a furnace will hold much more fuel than one that has only *three* sides of brick-work; and consequently the area for the bars may be much diminished. Indeed, one of the most important alterations of late years in the building of inclosed fire-places, is that of reducing their length to one half of the former dimensions, and adding something in lieu of the length to the width. The advantages which arise from this alteration will easily be perceived. It was no uncommon thing formerly to build the fire-place of a furnace four feet long.

Besides, if the four sides of any furnace be sloped very considerably, so that its upper diameter be twice the diameter at the bars, there will never be any danger of such a furnace having a false draught through the bars; because whatever fuel is thrown in through the hopper, will fall on all sides towards the middle of the furnace, and form a uniform covering to the grating.

I have found it convenient to have the hopper on one side of a furnace and the ash-pit on another, or at the end of the furnace: by this arrangement the assistant can supply his fire without being annoyed by the heat of the ash-pit, which is considerable in large furnaces.

It has lately been found advantageous to have fire-bars much narrower than formerly. By this alteration a fire burns more regularly, being more equally supplied with atmospheric air than it could be in fire-places with bars three inches wide. Half that substance is sufficient for any fire-place.

Respecting the width between the bars, the space which I have found to be the best, is half an inch, and this is sufficient for a fire-place of any dimensions. By casting the bars with a shoulder at each end, exactly a quarter of an inch thick, as shown at fig. 4. in the plate of Miscellaneous Articles, it gives the proper opening.

Such furnaces as are designed for producing a great heat, should be furnished with loose bars of a considerable size, resting upon two or three strong bearing-bars; for all grates, or sets of bars cast together and united in one frame, will warp and twist, and are with great difficulty cleared of the scoriæ or clinkers. Joggle-bars, as they are called, or such as fall into distinct and separate notches, are also very inconvenient. It is seldom advisable to buy ready-made fire-bars, but it is more profitable for the proprietor of a manufactory to have a pattern in wood, for each kind of furnace, made to his own

mind, and to have all the bars of that size cast by it. The form of the bars which I have found most useful, may be seen in the plate of Miscellaneous Articles, fig. 5.

If such bars be fixed upon strong and plain bearers, they will have room to expand by the heat without bending; may easily be moved to the right or the left, to loosen the scoriæ; and may readily be drawn out of the fire-place at pleasure.

In building a large furnace I have found it convenient, when I have employed a hopper, to leave an opening of two or three inches immediately above the fire-bars, as long as the whole breadth of the fire-place; and such an opening may be easily made by inserting a strong bar to support the brick-work over it. Through this opening the workman can occasionally introduce a poker for stirring the fire and loosening the scoriæ, and through the same opening he can withdraw the bars for the sake of emptying the fire-place, or replace them, as he may have occasion.

When a fire-place is built after this manner, it will be convenient to have a deep ash-pit: then, if the workman wishes at any time to cool the furnace expeditiously, he can draw out the bars through the orifice above mentioned, and the whole contents of the fire-place will fall at once into the ash-pit.

At some very large steam-engines I have seen a fixed door and frame at the opposite end of the furnace to that at which they feed the fire, for the purpose of drawing out the clinkers of the coals,

without incommoding the man who attends the fire; but I know from experience that the construction just described will in the end prove to be the most convenient. The aperture, as it rises only three inches above the surface of the bars, will not injure the draught of the fire-place, because the bed of fuel which covers the bars will be always thick enough to stop up that opening completely. See Miscellaneous Plate, fig. 6.

I have already urged the importance of employing an ingenious and experienced bricklayer, for it will always be prudent and economical to have every furnace well built at the first; for such furnaces not only answer their respective purposes better, but they consume less fuel, and will frequently last three or four times longer than those which are built by an ordinary workman.

To effect this in the best manner, it is obvious that the materials should be of the best kind, carefully selected for the respective parts of the work, and calculated for that particular furnace which the proprietor wishes to erect.

There are, however, a few necessary instructions from which I have derived so much advantage in my own manufactory, that I should be inexcusable were I to neglect to mention them.

It is a common opinion, that if good fire-bricks be used in the interior of the fire-place and in the flues, any thing will do for the exterior, or for the solid part of the fabric. This is not strictly true, for I have found it advisable to have even the ex-

ternal parts composed of the best building bricks that I could procure; because close joints and compact work can only be made with such materials; and if the workman does not lay close joints, and make the whole fabric very compact, he can never be certain that the air will not find a passage into the fire-place through other channels besides the ash-pit. Besides, whenever a furnace is taken down to repair a fire-place, these bricks may be used again and again; whereas common *place-bricks* can never be taken down whole, and consequently are useless for a second erection.

Wherever an intense fire is required, bricks made with the best Stourbridge fire-clay should be used; the joints should be rubbed very close, and that part of the work should be laid, not with lime mortar but with good fire-lute.

The fire-lute which I have employed for many years, never having been able to discover a better, is made thus: Good clay two parts, sharp washed sand eight parts, horse-dung one part. These materials are to be intimately mixed, then beaten up with a little water, and afterwards the whole is to be thoroughly tempered like mortar, by treading it for a considerable time with the feet. Mr. Watt's fire-lute is a good one, but it is more expensive. Take, says he, porcelain clay from Cornwall (not pipe clay), pound it, and mix it to the consistence of thick paint, with a solution of borax, in the proportion of two ounces of borax to a pint of hot water.

For some purposes, Stourbridge clay alone is very suitable for imbedding fire-bricks, as it burns into a substance similar to the bricks themselves, and the whole furnace becomes like one solid uniform mass. The Stourbridge clay is of a very peculiar kind; it lies at a great depth in the earth, under the bed of coal, and is known to the workmen by the name of *clunch*. It is a gray clay, of a sandy nature, and better adapted for making large crucibles and fire-brick than perhaps any in Europe.

It is not generally known, but there are some brick-makers at Stourbridge, proprietors of the clay pits there, who will make bricks of any form or of any dimensions that may be desired. Some friends of mine have had an entire fire-place made with that sort of clay, agreeably to patterns sent for the purpose; and it was so contrived, that though the bricks differed in form and size, every piece had its appropriate place, and fitted the adjoining one with the greatest nicety.

For some particular purposes it will be worth while to go to this expense; for, when the several parts are put together with a thin mixture of Stourbridge clay, sharp sand, and water, the first fire that is lighted within the furnace, will burn the whole into one entire and compact body.

In putting up the large stills used in the distillation of nitrous and muriatic acids, I have been accustomed to have an abundance of old iron hoops laid within the solid brick-work, some on every

course; with the view of holding it together and preventing a strong fire from cracking it, or forcing it outwards;—but I am now of opinion that these are not of much use, excepting in chimneys and in the walls which form the flues, and where the brick-work is necessarily very thin; for even where a great number of hoops have been laid in, the work has sometimes cracked, and produced a false draught in the fire-place.

A better expedient, and one which I have lately adopted with great success, is that of laying four flat iron bars in the brick-work of each still, one on each side of the fabric, and at the height where the fire has most force. I have these bars three-eighths of an inch thick, and two inches broad, and of a length sufficient to extend the whole length or breadth of the mass of brick-work in which they are to be imbedded.

These bars are made by the smith to fit the places where they are to lie, and are bent at each end so as to clip the masonry and prevent its moving: but before they are bent there is a slit of about two inches made in the end of each, which enables the smith to divide so much of the bar and to turn one half up and the other half down, by which contrivance it binds two courses of brick-work instead of one. By referring to the Miscellaneous Plate, fig. 7, I trust the method of making these binding bars cannot be mistaken.

The irons being thus prepared, and the work brought up to the proper height to receive them,

the bricklayer places one on one side of the furnace and another on its opposite side, and then raises another course of brick-work all round the whole area. Two of the irons being thus built in, the two others are laid in the same manner on the other two sides of the furnace, and built in as before. By this arrangement the whole is secured in a very complete manner, and I see no reason to expect that any thing will give way till either the stills or the fire-places are entirely worn out.

These expedients are all designed for the purpose of making the work durable, and preventing a current of atmospheric air setting in towards the fire-place in any direction otherwise than through the ash-pit: but for the economy of fuel, it is of equal importance that the bricklayer should be careful in the construction of the chimney, on which the goodness of every furnace very much depends.

In determining the form, the size, and the height of a chimney, an experienced workman will have no difficulty; but it appears to me that a proper attention is not always paid to the thickness of the walls, or to the materials of which they are built.

No outer wall of a chimney, however small it may be, should be less than nine inches thick, but it would be better if they were fourteen or eighteen inches in thickness; and such materials should always be chosen as are the worst conductors of heat, provided they are sufficiently compact, and have no crevices for the admission of atmospheric air.

Speaking of materials which are slow conductors

of heat, reminds me that some improvement might be made in the construction of our large boilers and evaporating pans, as to their power of conducting heat. What could possibly be worse contrived for preserving the heat than the large iron pans of the soap-boiler, which generally stand three or four feet out of the ground without any casing whatever? Our soap-makers formerly boiled in wood. The French manufacturer boils in brick [112].

But to return to the construction of chimneys: it is not only requisite that a chimney should admit no atmospheric air through its sides, but it is also desirable that the sides of the chimney should not cool the smoke and heated air within it; for, the higher the temperature can be kept in the interior, the better will be the draught.

Whatever may be the situation of a chimney, it is always best to have it stand independent of the boiler, still, or furnace to which it belongs. It is best to build the chimney first, and when that is finished, then to erect the apparatus round it, as may be most convenient.

Some chimneys are placed at the back of a furnace, others over the door: some boilers are set immediately over the centre of the fire-place, others at a considerable distance from it: in some cases the still or the boiler is suspended over the furnace, so that the bottom is entirely exposed to the action

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[112] See Chaptal's *Chemistry applied to the Arts*. 8vo. London, 1807, vol. i. page 153.

of the fire, while in other instances the still is supported by brick-work, and only partially exposed to the fire: one is heated only by the flame and hot air which impinge against the bottom; others have split draughts and worm flues of different kinds; and each of these modes may be applied with advantage to some particular purposes. But, as a skilful workman will never be at a loss to decide these points, I hasten to offer a few remarks on the management of the fuel, previous to the consideration of the necessity of an attention to temperature in our manufacturing processes; which, although the last, is certainly not the least important branch of this interesting subject.

If a chimney throws out a large quantity of smoke, it is impossible there can be a proper economy of the fuel; for the smoke is occasioned by particles of the coal which ought to have been detained in the fire-place, and there consumed in the production of heat [113].

This loss is chiefly occasioned by too much coal being cast into the fire-place at once, which prevents any of it from being properly ignited; whereas, if a small portion were always thrown in at a time, and this suffered to become thoroughly inflamed, or half burnt out, before more were added, the combustion would then proceed regularly, more heat would

[113] What Dr. Black has said on this subject is worth the perusal of manufacturers; it may be seen in his *Lectures*, 4to, vol. i. page 312—316.

be produced, and not half the coals would be used which are now consumed. I have found it advisable not to disturb the fire burning in a closed fire-place, more than necessary. Coals should be put so as they may lie light upon the grate. These are points of considerable importance in every manufactory where many coals are burnt; but it is very difficult to induce ordinary servants to attend to it; because, when the fire-door is opened, there is less trouble in putting on two or three shovels full of coal at once, than in furnishing half a shovel full at a time, and that very frequently.

The effect of heaping an unnecessary quantity of coals upon a grate in a closed fire-place is very mischievous and detrimental. The great mass, instead of entering properly into combustion, only moulders away, or is carried in the state of smoke through the channel of the chimney into the atmosphere; and the heat which is produced by the coals, instead of rising up to the boiler, and doing its proper office there, is forced through the bars into the ash-pit, and entirely lost.

A workman who would attend to these particulars would save to his employer what would be equal to his own wages, in fuel; the work would be better done, and the effect produced with more certainty. Besides, when the fuel is burnt to such a point as to have become a kind of charcoal, and no more smoke is given off, instead of heaping fresh coals upon such fuel, the ash-pit door should for a time be shut, to prevent the access of cold air;

and the fuel, in this high state of ignition, should be left undisturbed, in order that it may have its proper influence on the matter submitted to its action. Practice alone can teach how long a fire should remain in this state: but it is of consequence to manage it thus; for whenever, after this treatment, a proper quantity of fresh fuel is added, this fresh fuel will sooner get into full combustion, and the whole of it will be effective.

I am desirous, however, of observing, that all these remarks are designed to apply only to such furnaces as are constructed in the usual manner; being aware that there are patents for erecting fire-places to consume their own smoke, in which the proprietors direct large fires to be made which will not require to be replenished with coals for many hours. Some of these expedients have already been referred to at page 152 of this volume.

I pass over many other important particulars respecting the management and economy of fuel in closed fire-places, because they have already been well considered and explained in excellent detail by Count Rumford, whose Essays may be studied with advantage by all those who are desirous of investigating this important subject [114].

Much might be done in the way of economy, by the employment of the waste heat which is now lost

[114] Rumford's *Essays*, vol. ii. Essay 6; and vol. iii. Essays 10, 11 and 14.

in the generality of manufactories, and which the proprietors, by a little reflection, might contrive to put to a good account.

In large buildings where it is necessary to have iron pillars to support the floors, how easy would it be, as these pillars are usually cast hollow, to convey heated air, or waste steam, from an engine-boiler through them, and thus warm extensive premises at no expense! There is a perfection peculiar to cast-iron pillars, that they may be made ornamental at a cheap rate; and hollow pillars for supporting a roof or floor, cost much less than those which are cast solid, and are still of sufficient strength.

A gentleman whom I know in the neighbourhood of Manchester erected a cotton-mill, several stories high, on this principle. The floors consist of a number of small brick arches, the abutments of which are supported by hollow pillars of cast iron, and these pillars are heated with steam, or kept cool, as he sees occasion. By this construction he also saves insurance, as there is nothing combustible employed throughout the building. After his example, many factories have lately been erected on a similar plan in various parts of the kingdom.

I have often noticed the vast loss of heat arising from the exposed state of most of the steam-engine boilers. There would surely be an advantage in building a wall round them, and covering them from the action of the weather. Thus there would be a hot room attached to every steam-boiler, which might be applied to many useful purposes.

In like manner, to those manufacturers who have

occasion for large quantities of coke, if they have coal in their neighbourhood that will coke, how advantageous would it be to put up a proper oven or two for the purpose, and apply the spare heat for burning lime, heating stoves, &c.! The heat that is usually lost is very considerable, and it is so intense that it might be made sufficient for almost any purpose.

In most cases of distillation, the liquid which comes over is run through a refrigerating metallic worm immersed in a vast quantity of water. The design of this is to convert the gaseous product into a fluid nearly as cold as the surrounding atmosphere, and which without this would be mostly lost in steam. Why might not the worm in many cases be passed through an intermediate vessel surrounded by the wort or other liquid which is intended to be distilled, and which by this means could be heated to a certain point in readiness for the still, and at no additional expense [115]?

In some of the West India Islands this principle is already acted upon. A worm is made to pass through the sugar-wash, and this heats it ready for the still, and thus enables the planter to draw more rum in a given time. It has been thought, however, that the principle might be applied with more effect, if the heated air and smoke from the fire-place were made to pass through the wash: and several sets of apparatus of this kind have been prepared in London for some houses in Jamaica. A

[115] An apparatus of this kind is shown at plate, No. 5.

drawing of one of these I have procured, and have had it engraved to accompany these Essays [116].

A great saving of fuel is also effected by the introduction of the dome and back copper. This vessel, which is used by some brewers for boiling their wort, is constructed like a common copper, except in the cover, which is made like a very broad-brimmed hat, turned up very high all round the edge.

When the wort within the copper boils, the attendant turns a cock and fills this broad gutter in the cover with cold liquor. The consequence of this is, that the cover being filled with many gallons of *cold* wort, it condenses the steam as soon as it is formed, and becomes itself heated to 170° or 180°. When the liquor acquires this heat, it is let off into the copper below, and the cover is refilled with cold liquor.

For safety, the crown of this cover is furnished with a weighted valve, from whence the steam may escape whenever the fire is greater than it ought to be. By having the wort thus covered all the time it is boiling, the fine aroma or peculiar and grateful flavour of the hop is entirely preserved; whereas in a common open copper it passes off with the steam. The saving of coals is also considerable.

These desultory observations on the economy of fuel having been extended much further than was at first designed, I must be more concise than I

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[116] See the plates, fig. 8.

otherwise would in describing those cases which have been selected as instances of the importance of paying an attention to *temperature* in the conduct of manufacturing processes, and with these I shall conclude this Essay.

There is no complaint so common among workmen, as that of processes sometimes failing which have usually succeeded, and this without any apparent cause. Scarcely do I recollect an instance of such failure, without having had reason to suspect that it arose in some measure from a want of attention to the temperature at which the process was conducted.

The distiller of ardent spirits knows how important it is to regulate the temperature of the refrigeratory, and that, if it rise above a certain degree, a portion of the distilled spirit will be dissipated in the atmosphere and lost: the glass-maker is aware that the goodness of his glass entirely depends on the care with which he reduces the temperature in the process of annealing: the horticulturist will also acknowledge that it would be absurd to expect success in his crops without attending to the heat of his beds, his walls, or his vinery: and why should the manufacturer imagine that there can be any chemical operation in which the degree of temperature is of little moment?

Formerly the brewer had no certain guide to determine when the water was cool enough for mashing the malt, and the fermentation of the wort was conducted only by guess, which occasioned frequent

failures and disappointments. He has, however, in the thermometer, now found an unerring guide.

In the preparation of vinegar, the manufacturer depends chiefly upon the sun for the additional temperature which he requires for completing his process. In large establishments, therefore, a great space of land is allotted for the exposure of the casks to its influence. There are, however, some proprietors of vinegar-yards who have found by experiment that the vinegar sooner acquires its maximum of acidity by being kept in a more regular temperature than can be obtained by the sun's rays, since hot days are frequently succeeded by very cold nights. Such manufacturers, having erected stoves and prepared rooms for the reception of the vinegar, keep it at that exact temperament which they have proved to be best adapted to the process, and find they can finish the work in less than two-thirds of the time usually required for perfecting the business [117]. How easy then would it be for every manufacturer to make this experiment for himself, and ascertain by a few trials what is the proper temperature for conducting the process to the greatest advantage, and in the least time!

What an accession to the stock of knowledge might be expected, if Government would give every possible encouragement, by medals, honorary rewards, and prizes, to those who make the most important discoveries in the line of their several pro-

[117] See Essay I. pages 33 and 34 of this volume.

fessions! "A sovereign, indeed, ought never (as a continental writer expresses himself,) to be the subject of regret for giving pensions to those, who having the necessary talents, consecrate themselves to studies useful to their country [118]." In China, the emperor is every year informed what farmer is the most distinguished in the improvement of his lands, and he makes him a mandarin of the eighth order [119].

Few processes require a more strict attention to temperature than the crystallization of salts. Some require a hot, others a cold situation; and I am not acquainted with any one species that does not give finer crystals when set to shoot at its own peculiar degree of temperature, in preference to all others.

The solution of a salt is also as much governed by temperature as its crystallization: and it is on a knowledge of this principle that the separation of one species of salt from another generally depends. The refining of saltpetre may be mentioned as a familiar instance. In this operation the crude nitre, or rough petre as it is called, is dissolved in hot water, nearly to the point of saturation. Part of the water is then evaporated by boiling; and as the liquor becomes concentrated, the muriate of soda, which is nearly as insoluble in hot as it is in cold water, separates itself from the nitre, and precipitates.

[118] M. Carrard's *Prize Essay, on the Spirit of Legislation*, 8vo, London, 1772, page 220.

[119] Montesquieu's *Spirit of Laws*, book xiv. chap. 8.

This is successively removed as it falls, and the boiling is continued till the operator is satisfied that all the muriate has fallen: the hot liquor, which contains the purified nitre in a state of solution, is then drawn off into coolers, that salt may crystallize.

In the manufacture of earthenware and porcelain many different temperatures are required, according to the nature of the articles, and the progress which has been made in their preparation. In connexion with this subject it may also be observed, that the large glass-house crucibles (according to the present management) require two years for drying, previously to their being submitted to the heat of the potter's oven; and that any kind of earthenware which takes frost during its drying, will inevitably prove very brittle.

In the tanning of hides it has always been known that the process went on much better in summer than in winter. How natural then is it to have recourse to artificial temperature! Mr. Brewin, an ingenious tanner in the Borough of Southwark, is the only person that I know of who has profited by this palpable improvement in the manufacture; and he will doubtless be amply repaid the expenses which have been incurred in erecting stoves and building flues, to convey extra heat to the pits in which the hides are steeped; for the quality of his leather is much improved, and the process is now shortened by several months.

Had this experienced tanner resided in France

under the administration of the great COLBERT, who annually set apart forty thousand crowns [190] for the encouragement of ingenious manufacturers, he would doubtless have received a public remuneration. In like manner, in Persia, where the lands require to be watered artificially, if any one has the art of conducting water to a place where it never was before, he has the enjoyment of the advantage of it for five generations.

The working cutler, when he has iron and steel to forge of good qualities, knows that his sole dependence for the excellence of the tools he fabricates, is upon the degree of temperature at which the work is conducted in its different stages. He knows that a sword must be tempered at a heat very different from a pen-knife, an adze different from a saw, and a watch-spring different from a lancet; but the pyrometer has not yet been employed by these manufacturers, and to this circumstance the difficulty and uncertainty of procuring a good edge tool may be attributed. This subject will, however, be further treated of, and some hints for the improvement of the present methods of tempering will be given in the Essay on Edge-tools, which constitutes a part of these volumes.

Neither has the thermometer been made use of by the tallow-chandler, although it is evident that he ought never to make any candles without em-

[190] *Prize Essays, on the Spirit of Legislation*, 8vo, London, 1772, page 341.

ploying that instrument: indeed, the chipping of the outward coat of candles is owing entirely to the neglect of this circumstance, not to say that there is reason to believe that the tallow is often injured, *in the first instance*, by melting it at an improper heat.

The seed-crushers and makers of certain vegetable oils often suffer considerably in consequence of their processes being conducted at an improper temperature. One instance may be taken from the operation of drawing linseed oil. The workman knows that unless the seed be in some measure heated, the oil will not flow; he therefore roasts it over a charcoal fire, and loses ten or fifteen per cent. in weight by that operation. If there be the least want of care, the loss will be much more considerable. In ascertaining by actual experiment what is the temperature that is really necessary, this process, by a proper arrangement, might be managed with as much certainty as any other.

A bushel of foreign linseed weighs about 50lbs.; a bushel of English seed is usually from 60 to 62lbs. In roasting over a charcoal fire to prepare it for the mill, the former generally loses 5½lbs. and the latter 6lbs.; that is, when the oil which comes from the mill is weighed with the oil cake, there is commonly this deficiency. It strikes me, that if the seed were to be heated by steam, no part of it would burn, and consequently the loss would be very inconsiderable. A still greater saving might also be introduced into this manufactory, were the oil cake

itself to be heated by steam; because this would enable the operator to grind it a second time, and thus express from it more of the oil.

An attention to temperature is also of great importance to the dealer in Greenland whale oil, who might increase the profits of his trade very much by preparing his oil for sale when the weather is suitable for the operation. This kind of oil is always purified by passing it through large flannel bags, which retain the impurities, and suffer the finer parts to percolate through them. When the oil has undergone this treatment, it is called *bagged* oil, and is then deemed fit for sale. At a low temperature, a considerable quantity even of this latter kind would concrete, and might be separated by similar means; whereas in a warm atmosphere this dissolves, and, being less inflammable, very much injures the oil for burning.

By proper attention to this circumstance, all the oil which is designed for burning might be very much improved, and the portion thus separated from it, would be worth more to the soap manufacturer for making yellow soap, than similar oil which had not undergone this process. I conceive that an oil-merchant would do well always to bag different oils in different seasons; though many experiments might be necessary before it could be ascertained what was the exact temperature at which the respective kinds would most copiously deposit this feculence.

Madder is an article of great consumption

throughout Europe. It is chiefly cultivated in Holland, where it enriches the farmer, and is a considerable source of profit to the Dutch merchants. Plantations of madder have also been made in this country, and the thing has been attempted in France; but it failed, as I understand, in both countries, from the circumstance of the growers not knowing the proper temperature at which the stoves ought to be kept for drying it.

This might surely be ascertained by common means; and if the circumstance of making experiments during the time of harvest should be an objection, how easy would it be for an enterprising agriculturist to procure a person from Holland to give him the necessary instruction!

When the French minister was informed that the workers in silk were in the habit of importing organized silk from Piedmont, to serve as a chain [121] for their stuffs, because they were ignorant of the method of drawing the silk from the cocoons, he did not hesitate about the proper remedy, but invited the celebrated Vaucanson into France, who not only gave him the information he wanted on that particular point, but invented a machine for platting the stuffs of gold and silver, and giving them the brilliancy of those of the Levant. Thus, by the aid of an ingenious foreigner, the French

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[121] The French knew before how to prepare their own silk for the woof, but were unable to make it good enough for the chain.

nation acquired a new and very considerable branch of commerce[122].

In dyeing woollen cloths with indigo, the blue is more intense, and the colour more permanent, when the vat is used cold. Of these facts no dyer is ignorant; and yet it is a common practice to employ heat, because this makes the indigo go much further, and the colour strike quicker. I would suggest whether it is not likely that there may be one certain temperature at which the indigo would be completely exhausted, and yet the permanency of the dye not impaired.

In the china-blue dipping, one of the processes of calico-printing[123], the temperature of the lime-vat is of the utmost importance. When the lime is slacked for this purpose, and the vat is prepared with it, there can be no certainty that it will properly fix the printed indigo in the fibres of the cloth, unless it be left at rest till it become as cold as the surrounding atmosphere. To conduct this process with certainty, a thermometer is indispensable; for, as I have understood, the indigo is either fixed or spoiled at the first immersion.

Printed calicoes sometimes sustain an injury by not being stoved at a proper temperature. The common heat of the stoves is about 90°. If they are suffered to rise much above that standard, there

[122] Carrard's *Memoir, presented to the Literary Society of Berne*, page 328.

[123] For an explanation of this process, see the Essay on Calico-printing; or the article "China-blue dipping," in the General Index.

is great danger of the acids which have been employed in forming the printed colours injuring the fabric of the cloth, and rendering it tender. On the contrary, some of the colours would spread or enlarge, and perhaps run the one into the other, if the temperature of the stove were allowed to fall, and the calicoes to become cold before they were cleansed of the superfluous mordants.

In the neighbourhood of Rochdale in Lancashire, and in some parts of Yorkshire, the clothiers dye yellows and oranges with the common heath, or ling as it is sometimes called, which is taken from the moors and uninclosed common fields. They mow it when in full flower, about the time of hay harvest. It is spread out to dry as they do hay, and is then laid up in ricks or barns in the same manner.

This vegetable produces, by means of a tin mordant, a more beautiful yellow on woollen cloths, than either weld, quercitron-bark, or fustic; the colour being not only brighter, but much more intense than what can be procured from either of those dyes. This colour is, notwithstanding, of very little real value, because it will not bear the action of the sun and air like that produced from weld, nor even so well as the yellow from fustic.

The manufacturers, therefore, invariably dry the goods which are dyed with heath, under cover and in the shade. A very large quantity of coarse cloths, called *bockings*, are dyed with this cheap vegetable substance for the American market; and as the

ling has been used in dyeing these kinds of cloth, only a few years, I fancy the American consumers have not yet learnt to distinguish the goods which are dyed with heath from those which are dyed with fustic. I relate these circumstances merely for the purpose of suggesting whether there may not be some particular temperature at which the heath may be used so as to give a *permanent* dye.

A very excellent yellow may also be given by the quercitron-bark; but if a printer of calicoes be desirous of getting the very finest colour, it can only be procured by making the decoction of the bark, at a very low temperature[194]. If, for instance, the colour be extracted from the wood by a heat of about 86°, the goods may be dyed with this decoction at 200° or 205°; but if the colour be extracted at a higher temperature than 86° or 90°, the liquor will inevitably acquire more or less of a brown colour. A high temperature separates the tan[195] as well as the colouring matter, and the tan which is developed, much deteriorates this very useful and beautiful dye.

The quercitron-bark is also employed in dyeing *woollen* cloths, and for this purpose the dye may be extracted at a temperature somewhat higher than

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[194] The most permanent yellow dye we know of is procured from the *weld*. I have often made experiments on extracting the colour from this plant, but I never observed that the beauty of the dye was in the least impaired by digesting the plant in water at any temperature, or even by boiling it.

[195] I have found that a small portion of muriate of tin will precipitate the tanning principle from vegetable decoctions; but I

it is ever advisable to use it for printing calicoes: but if these woollen goods be afterwards *hot* pressed, which is a customary process in finishing them for the market, the colour will be changed to a brown; whereas, by submitting the same kind of goods to the action of a *cold* press, the colour is never impaired. Here the variation in the treatment produces such difference in the effects, that the most unscientific workmen are absolutely compelled to attend to temperature.

It has been discovered that the solvent power of water in some cases is very much increased by giving it a temperature above that of 212°. For instance, if it be heated in closed vessels to 220°, it is much more efficacious in bleaching cotton goods than water is, merely at a boiling heat. This, however, can only be accomplished by pressure. I mention the circumstance in this place, because I conceive the principle to be important, and that it might be applied with advantage to many other useful purposes. It is true, that this additional temperature can never be imparted to water without employing artificial pressure, as I have remarked; but we know so little of what changes might be effected in the properties of bodies by treating them with caloric under the pressure of several at-

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have not yet made such experiments as will warrant my giving particular directions. In cases where it would be prejudicial to employ muriate of tin, a little isinglass might probably be substituted with propriety, on the principle of the affinity which tan has for gelatine.

mospheres, that nothing surely can be more deserving of a diligent and patient investigation.

It is well known how difficult it is to fuse chalk or marble, because, when these substances acquire a certain temperature, the carbonic acid escapes, and they become lime. Sir James Hall, nevertheless, effected the fusion of chalk at a very moderate temperature, by employing a sufficient pressure to prevent the separation of its carbonic acid and water, and in this way he converted the chalk into perfect marble. The detail of these very interesting experiments will be found in the sixth volume of the Edinburgh Philosophical Transactions.

Some very unexpected results have also been produced by the different methods of cooling certain mineral substances[196] which had been reduced to a state of fusion. About seven hundred weight of the *Rowley rag*, a species of basalt, was fused in a common reverberatory furnace, by the late Mr. Gregory Watt, who carefully noticed the changes which it underwent during its different stages of cooling, and communicated the result of his observations to the Royal Society.

This stone is found in the neighbourhood of Rowley in Staffordshire: the village stands upon it. It is of a dark gray colour, and, according to Dr. Withering, it consists of 48 silex, 32 of alumine, and 20 oxide of iron. It is so hard, that

[196] An Account of Sir James Hall's experiments on the cooling of basalt, may be seen in the fifth volume of the *Transactions of the Royal Society of Edinburgh.*

Birmingham and some other towns in the neighbourhood are paved with it. It is sometimes employed to mix with the materials for making the common black bottle-glass.

The basaltic mineral in the experiment just mentioned, melted easily; and when a portion of it was taken out in a state of fusion, and cooled quickly, it produced a very hard, opaque black glass [127]. When the fire had been continued for six hours, the chimney was closed, and the whole surface of the liquid mass remaining in the furnace was covered with heated sand; after which, eight days elapsed before the whole substance was sufficiently cool to admit of examination.

On removing the indurated mass from the furnace, it exhibited very different appearances, according to the varied action of the heat; and that which had cooled the slowest, was of a dull dark gray colour, very similar in appearance to the original rag-stone. In one case a rough granulated substance is produced, and in the other a shining and smooth glass; and though the difference is so striking, it is occasioned entirely by the variation in the length of the time allowed to this matter for its reduction of temperature.

I have examined some of the specimens which

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[127] I believe any of the common bottle-glass may be reduced to a stony substance, by first melting it, and then cooling it very slowly; and that it may afterwards be restored to its shining, vitreous appearance, by remelting it, and then abstracting the caloric with rapidity.

were taken from the furnace at different times during the experiment; and the difference in their appearance is as great as could well be conceived. They were presented to me by a relation of Mr. Watt, soon after the experiment was performed.

From the discovery of these facts, Mr. Watt has endeavoured, in a very philosophical way, to account for the regular figure of the natural basaltic columns, and even for their regular articulations. His reasoning is extremely ingenious; but the reader must be referred for further particulars to the memoir itself, which may be seen in the Philosophical Transactions for 1804.

It has been ascertained that steel contains more carbon than wrought iron, though less than cast iron. From the knowledge of this fact, an ingenious manufacturer at Chesterfield has invented a new mode of making cutlery, and certain other implements in cast iron, and afterwards converting them at pleasure to a substance resembling either wrought iron or steel. This he effects by burying the respective articles of cast iron in a mass of native oxide of iron previously pulverized, and submitting the whole to a long continued heat.

In this operation the oxygen of the oxide combines with the superfluous carbon of the cast iron, and, forming carbonic acid or carbonic oxide, escapes, and leaves the metallic articles in the state of wrought iron or steel, as the operator desires.

This process, which in general answers very well, sometimes will entirely fail, and disappoint the

artist. This I should ascribe to its having been conducted at an improper temperature. For if too little heat be given, the native oxide does not impart its oxygen; and if the heat be too intense, or continued beyond the proper time, too much of the carbon will be abstracted, and the articles of cutlery which were designed to have the properties of steel, will be reduced to the state of soft wrought iron. A good manageable pyrometer would enable the operator to escape these disappointments.

In the decomposition of the sulphuric salts for the production of alkalies, a business which I formerly carried on to a considerable extent, I was often perplexed by a similar difficulty. Whenever I could superintend the process myself, I could judge tolerably well of the progress of the operation from the appearances which the materials exhibited within the furnaces; but when the management of the process was left entirely to the workmen, the operation was sometimes very ill conducted, and the alkaline product was of very little value. For, if a sufficient heat had not been duly maintained, the sulphates were not decomposed; if the decomposition had taken place, and the fire was then suffered to go down, the sulphates would in a great measure be regenerated; and if, during the latter part of the operation, the heat became too intense, then the nascent alkali was elevated, and passed away through the chimney, to be dissipated in the atmosphere. Had I been in possession of a good pyrometer, all these evils might have been avoided.

I know of nothing that better deserves a premium than the invention of a simple and cheap pyrometer, calculated for general use, and applicable to the highest temperatures. That invented by Mr. Wedgwood was an instrument of this kind, but unfortunately the method by which he prepared the small cylinders of argillaceous earth is entirely lost. This reminds me, that Guyton has proposed platinum as a material of which a useful pyrometer might be constructed, as it is not fusible at the heat of our furnaces, and would not be eroded by any of the gaseous products evolved by the most intense fires [128].

The want of a good pyrometer is severely felt by the manufacturers of Birmingham. Cases daily occur of losses sustained in consequence of their not knowing how to ascertain the precise degree of heat in high temperatures.—A single instance will be sufficient to explain my meaning.

It has been customary to fit up the best fowling-pieces with touch-holes of gold, because those of iron or steel are soon eroded and worn away by the sulphur of the gun-powder, which unites with this metal and converts it to a brittle sulphuret.

Nothing can be easier than to mould these gold touch-holes properly, and also to fix them firmly within the gun-barrel; but there is an after-process to be performed, which is attended with consider-

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[128] See *Annales de Chimie*, xlvi. page 276; or Nicholsons's *Journal*, vol. vi. page 89.

able difficulty. One of the last operations in finishing a gun-barrel is that of hardening the breech, which can only be done by submitting it to a high degree of heat; and if ever the precise degree that is necessary for the process be exceeded, it is ten to one but the gold melts, and the manufacturer has to replace it with another touch-hole.

When such an accident does occur, the workman has the trouble of again softening the temper of the barrel before he can fix another touch-hole to it, and consequently the same expense and risk of hardening it must be incurred, besides the loss of time. Owing to these inconveniences, the gun-smiths have nearly discarded the use of gold, and now make the touch-holes for the best fowling-pieces of platinum, although they cost nearly double the price. I have been informed that Mr. Manton, a very eminent gun-smith of Dover-street, was the first person who employed platinum for this purpose.

In heating madder for dyeing what are called army-reds, the intelligent dyer well knows that he ought to increase the temperature of the liquor very gradually, and therefore he never attends the operation without carrying a thermometer with him. The scientific gardener has one degree of heat for his cucumber frames, another for the vines, a third for his pinery, and others again for the different exotics, as his experience has prescribed. The sugar-refiner has a stove at one temperature for the bastard sugar, at another for the loaves, and at a third for the candy. The maker of varnish, the

general manufacturing chemist, the hatter, the calenderer, the colour-maker, and a variety of other artists, are all dependent on the habit which they have acquired of seizing some one particular temperature for the success of their respective operations, and often without being conscious of their obligation to that circumstance. Even in the manufacture of cheese and the churning of butter recourse must generally be had to an increased temperature; neither will the dough properly ferment, which is designed for making bread, unless it be exposed to a temperature generally higher than that of the atmosphere in this latitude.

I trust, however, that enough has now been offered to induce every manufacturer, who may peruse these loose hints, to apply them to his own business, and to consider, whether some of his peculiar processes might not be very materially improved by a variation of the temperature at which they have usually been conducted. This is the chief object I had in view in composing this Essay; and as all the principal observations are founded upon experience and the best information I could procure, I entertain some confidence that it will be acceptable, and prove highly useful, to the British manufacturer.

The superior knowledge of our manufacturers has been the great source of our excellence as a commercial nation; but there is a danger, amid the growing intelligence of the age, of our losing this proud preeminence, unless some spirited individuals, in every class of society, aim at informing

the public mind, and exciting that emulation among our respective artists, which is sure to stimulate their exertions and lead them on to perfection.

The period I trust is not far distant when a British minister would incur a very serious responsibility were he to neglect to reward any individual who had been the means of improving the manufactures of the country. PERICLES, the great Athenian statesman, who valued himself on the circumstance that during the whole of his administration he had not occasioned the death of a single citizen, established new games and prizes with the sole view of exciting a noble emulation among the Athenians; and while he held the reins of government the arts were carried to the highest point of excellence and perfection. The ancient Romans, on the contrary, restricted commerce and the arts;—they would not allow a senator to have a vessel at sea that could contain more than forty muids [130].

The great COLBERT, who was secretary of state in the reign of Louis XIV., directed, that the different French artists should expose their works every year to the eyes of the public, and that the public should adjudge a crown of honour to him who should most excel in the beauty and execution of his work. In various ways he animated and recompensed all who distinguished themselves, and his zeal for the great and the useful, was followed by the most brilliant success.

[130] The nobles of Venice even in the present times are not allowed to exercise commerce.

A subsequent administration patronized the philosophical REAUMUR, a man of great genius, who was indefatigable in his experiments to discover the composition of the Chinese porcelain, and who also carried off from the Germans the art of refining tin, and of converting iron into steel.

It would be difficult indeed to say what a people might not do by proper encouragement. In China, two of her finest and most fertile provinces (Kiang-nan and Iche-kiang) were gained from the sea by the industry of her inhabitants.

The merchants and manufacturers of England are proverbial for their enterprise and assiduity; and, if not crippled by excessive imposts, which paralyse the exertions of any people, nothing can prevent their having a full share of the commerce of the universe. That minister, therefore, must surely be ignorant or infatuated, and extremely culpable, who, when relieved from the perplexities of war, does not pride himself in aiding the genius, strengthening the hands, assisting the efforts, and increasing the means of such a laborious, industrious, and ingenious set of men as those who now so effectually support the character of the British nation.

ESSAY III.

ON

SPECIFIC GRAVITY.

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ON

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NOTHING can be of more importance to those who are entering on the study of chemistry, or desirous of examining the works of nature with accuracy, than a competent knowledge of the most convenient methods of taking the specific gravity of bodies.

Every man of science who has had much intercourse with the world, must have met with many intelligent people who are entirely ignorant of this subject; and wherever this is the case, it must be a material obstruction to their making any considerable advances in chemical knowledge.

It may perhaps appear superfluous to those who are conversant with chemistry, to undertake to explain what they themselves so well know, that they cannot so much as recollect the time when it was not known to them. There are, however, many

who are so entirely unacquainted with any of the modes of taking specific gravities, that they cannot even explain how absolute differs from specific weight: to such readers therefore no apology will be necessary.

Gravity may be defined to be that property inherent in all bodies which gives them a tendency towards the centre of the earth, and which enables us to measure the quantity of matter in any particular mass, by means of the balance. The amount which the balance thus indicates is said to be the WEIGHT of that body. This is what we call the *absolute* weight[1], or the absolute gravity of any particular substance, to distinguish it from the *specific* weight; or, as it has sometimes been called, its *comparative* gravity.

By SPECIFIC GRAVITY is meant the relative weight of any substance as compared with the weight of an equal bulk of another, which we agree to call the standard; for which purpose all nations have fixed upon water as unity. Thus the specific gravity of one body is less or greater than that of another,

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[1] An elaborate memoir, entitled "An account of some endeavours to ascertain a standard of weights and measures," by Sir George Shuckburgh Evelyn, Bart., will be found in the *Philosophical Transactions*, vol. lxxxviii. page 133.

[a] "Just balances and just weights shall ye have, I am the Lord your God." *Leviticus*, xix. 36. "The spear-head of Goliath weighed six hundred shekels of iron." 1 Samuel, xvii. 7. "Absalom weighed the hair of his head two hundred shekels after the king's weight." 2 Samuel, xiv. 26. "Who hath weighed the mountains in scales, and the hills in a balance?" Isaiah, xl. 12.

though their absolute weights may be the same. The specific gravity of a body is in a direct ratio of the mass, and in an inverse ratio of its bulk.

The method of ascertaining quantities by means of the balance was known in the remotest ages[2]; but a long period probably elapsed before mankind acquired any correct idea of distinguishing between the absolute and the comparative weight of bodies[3].

Even the great Archimedes, who lived only in the third century before Christ, knew of no method of taking the specific gravity of the precious metals, so as to ascertain the amount of their adulteration; and it was only by long thought that he was at last enabled to succeed. The mode which he devised is minutely described by Vitruvius[4], and his account has been translated for the General Biographical Dictionary, under the article "Archimedes[5]."

When Archimedes had made himself acquainted with the nature of specific gravity, he wrote two books entitled "*de Insidentibus Humido*," of which the Latin translation is yet extant, though the original in Greek be lost[6].

The letter from Synesius to the female philoso-

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[3] Pliny ascertained the relative weights of several sorts of grain, as may be seen in his *Natural History*, book 18. Vitruvius, who was contemporary with Pliny, has also given the weight of a known measure of mercury, viz. that of four Roman sextarii. *Architectura*, lib. vii. cap. 8.

[4] *Architectura*, lib. ix. cap. 3.

[5] *Biographical Dictionary*, vol. i. page 434.

[6] This lost work of Archimedes is said to have been recovered from an Arabic translation. It was republished in Latin by Fredericus Commandinus, at Bononia, in 1565.

pher Hypatia, shows that it was understood how to take the specific gravity of water so early as in the fifth century [7]. And Quintius Rhemnius Palæmon, who was a teacher at Rome in the reign of Tiberius, has in his fragment entitled *De ponderibus et mensuris*, made the following observation on the comparative specific gravities of water, wine, oil, and honey.

——— Libræ, ut memorant, bessem sextarius addet,
Seu puros pendas latices, seu dona Lyæi,
Addunt semissem libræ labentis olivi,
Selibramque ferunt mellis superesse bilibri.

On the revival of learning in Europe, we hear nothing of the examination of bodies by their specific gravities, until this was recommended by Lord Bacon and the Honourable Mr. Boyle. The oldest table of specific gravities now extant, was compiled by the first of these eminent philosophers. It will be found in his tract entitled *Historia densi et rari*, printed in the second volume of his works in folio, London, 1741, page 69. The methods which he pursued in order to form this table were as follow. Having formed a perfect cube of pure gold of an ounce weight, he caused cubes of the same size to be made of various other materials, and by weighing these against each other he ascertained their relative specific gravities. In regard to fluids, he found their specific gravities by weighing them in hollow

[7] See the Essay on Water; or the Index, article Synesius.

cubes of silver, which he had made for this express purpose.

Half a century afterwards Mr. Boyle wrote on the subject, and showed the advantages which a student must derive in his examination of minerals, and in his other chemical pursuits, from the habit of paying a constant attention to the specific gravity of the several substances which should come under his observation. Other philosophers of Britain then caught the idea, and the practice has been continued ever since by a few illustrious men, such as Newton, Hales, Black, Lewis, Cavendish, and Priestley; and now by all who make any pretensions to cultivate the sciences.

The experiments by Sir Isaac Newton on specific gravity, appear to have been undertaken with a view to his inquiry respecting the densities of bodies when compared with their several refractive powers. The result of these experiments led him to conclude that those transparent substances which are the most refractive, always contain some combustible substance. Hence he concluded that water must be a compound body, a conjecture which has been most fully verified by subsequent discoveries, and shows what extraordinary powers of comprehension of mind he must have possessed, for at that time every philosopher supposed water to be one of the undecomposable bodies, or simple elements of nature [8].

[8] Sir Isaac Newton's table of specific gravities, consisting of 22 articles, was published in his *Optics*, 4to, London, 1704.

The introduction of this art must, however, have been somewhat later on the continent of Europe; for an eminent French chemical writer tells us, that it was never employed with them in the analysis of minerals till the time of Buffon [9], who was the first to acknowledge its importance, and render it useful [10].

Although Buffon may have been the first philosopher in France who attended to specific gravity in the analysis of minerals, it was employed elsewhere in the examination of metals and for other purposes many years before his time.

Marinus Ghetaldus, a nobleman of Ragusa, published a treatise at Rome in 1603, entitled *Promotus Archimedes, &c.*, wherein he gives a comparison between the specific gravities of water and eleven other different substances. In the year following, Baptista Villalpandus published his *Apparatus Urbis Hierosolymitani*, in which he exhibits a table of the proportional weights of all the metals which were then known, and of some other substances. Marinus Mersennus printed a similar table at Paris in 1644, in which he makes gold 100, and water 5½. In the year 1699, M. Homberg read to the Royal Academy of Sciences at Paris, a memoir, showing "how to discover exactly how much one spirit weighs more than another [11]."

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[9] This illustrious man spent fourteen hours a day in study. At five in the morning he retired to a pavilion in his vast gardens, and he was then inaccessible. Prince Henry of Prussia called this retreat the cradle of natural history.

Specific gravity may be considered to be merely another term for the comparative density of bodies; and as the nature and properties of a great variety both of solids and fluids depend in a great measure upon their density, nothing surely can be of more consequence in the examination of natural and artificial substances, than an attention to their specific gravities.

It is thus that the purity of some of the metals, and the value of many liquid preparations, are determined; and thus only can we decide the classification of some minerals when they are not subjected to a regular analysis.

To determine the purity of ammonia, the goodness of alcohol, the strength of other ardent spirits, and the concentration of the mineral acids, their manufacturers entirely rely upon the respective indications which their specific gravities afford them.

In the preparation of alkaline lyes for the manufacture of soap, the operator has to determine the quantity necessary for each operation, and the specific gravity of the solution is his only guide. The makers of Roman vitriol, Epsom, Rochelle, Glauber and other salts, have no proper criterion for ascertaining the strength of the several liquors which they have prepared for crystallization, but that of their specific gravity.

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[10] Fourcroy's *System of Chemical Knowledge*, vol. ii. page 359.

[11] See *Hist. Roy. Academy* for 1699, or the 4to *History of the Works of the Learned*, vol. iv. 1702, page 652. Professor Musschenbroek of Utrecht published a large table of specific gravities in his *Elementa Physicæ*, 8vo, Leyden, 1734.

The strength of a variety of metallic solutions, and the concentration of many of the fluids which are employed in chemical operations as solvents for other bodies, can be decided only by the same means.

The makers of oil of vitriol have no other way of knowing when the acid is in a proper state to be removed from the chambers of combustion; the calico-printer, who concentrates his own lemon-juice, has nothing else to direct his decision in determining whether the citric solution be fit for this or that particular style of work; nor does the modern bleacher, who is careful in his operations, ever dare to use the liquid oxy-muriate of lime, till he has reduced it to that particular specific gravity at which he knows it may be used with safety.

Even the malleability, tenacity, and hardness of some of the metals, and the volatilities of many fluid substances, may be ascertained or conjectured by an attention to their respective specific gravities; but to enumerate more individual instances would be useless, as I conceive the importance of the subject under consideration must now be fully apparent [12].

It has been before remarked, that specific gravity is only another name for comparative gravity, the absolute weight of the substance under examination being always compared with that of some other

[12] Those who wish to see more on the utility of the knowledge of specific gravity, may consult Boyle's *Medicina Hydrostatica*, or Cotes's *Hydrostatical Lectures*, 8vo, London, 1775, page 82.

substance exactly of an equal bulk. In fixing this standard, water presented itself as the most convenient substance; and this, as I before stated, is now generally employed as the datum from which all calculations of specific gravity proceed, water at the temperature of 60° being always called 1.000.

Mr. Boyle, in his *Medicina Hydrostatica*, states that a cubic inch of clear water weighs 256 troy grains, or 442368 grains to the English cubic foot; but probably this was not distilled water. According to the experiments of Professor Robinson of Edinburgh, a cubic foot of distilled water at the temperature of 55° weighs 998.74 ounces avoirdupoise, of 437.5 grains troy each, which is only one ounce and a small fraction less than 1000 avoirdupoise ounces, so that rain water at the same temperature will weigh, as has been stated elsewhere, pretty nearly 1000 ounces [13].

Some excellent directions for the choice of an accurate pair of scales for philosophical purposes will be found in Dr. Ure's Chemical Dictionary, article Balance; and a very ingenious mode of making most minute and accurate weights is described by Lewis, in his Commerce of the Arts, p. 544. It will therefore not be necessary for me to enlarge on this branch of the subject. Decimal

[13] For further information consult Mr. John Dalton, "On the Density of Water," in Nicholson's *Journal*, vol. x. p. 93; Count Rumford, in the same work, vol. xi. page 225; or Dr. Kelly's *Universal Cambist*, 4to, London 1811, vol. i. page 260.

weights are the most convenient for general philosophical purposes. These are usually sold in boxes from 1000 grains down to the tenth of a grain.

In estimating the specific gravity of fluids, it is usual to procure a phial with a narrow neck, to fill this phial up to the small part of the neck with two, four, eight, or some determinate and easily divisible number of ounces, or any other known weight, of pure water, and then to mark the neck of the bottle with a diamond, precisely at the spot to which the water ascends within it. The bottle being thus prepared, and the quantity of water which it holds up to the fixed mark being remembered, it is ready for use.

When any liquid substance is to be examined, all that is necessary is to pour into the bottle as much of the liquid under examination as shall exactly rise up to the mark on the neck, and then to weigh it accurately, and calculate the difference by the common rule of three. For instance, if it weigh exactly the same as an equal bulk of water, it is said to be of the specific gravity of water. But if the bottle hold four ounces of water, and the same measure of some other fluid should weigh *six*, it is evident that this fluid is half as heavy again as water, and water being 1.000, this fluid will be noted to be of the specific gravity of 1.500; because 4 : 6 :: 1000 : 1500. The bottle usually employed by the soap-boiler, to ascertain the strength of his alkaline lyes, is of this kind.

Another method of ascertaining the specific gra-

vity of fluids, is by noting the weight of some solid, such as a cube of glass, in distilled water, and then weighing the same substance in the liquid to be examined. These weights should be noted in grains, and by dividing what the solid loses in the fluid by what it lost when it was weighed in the water, the quotient will be the real specific gravity of the liquid. The specific gravity of fluids is also found by the areometer, a mode that is attended with much less trouble than either of the former, but it is not likely in all cases to be equally accurate.

This instrument is a graduated glass tube, with a bulb at one end of it, and so contrived, by being balanced with mercury or lead, that it may swim in the fluid, in a perpendicular position. The specific gravity is shown by the degree marked on the stem of the instrument, to which it sinks in the fluid to be examined, and this will consequently always be lower in proportion as the liquid is lighter. The areometer of Baumé, which has long been the instrument in common use in France, is upon this construction.

The areometer is an instrument of great antiquity. It was formerly supposed to have been invented at the close of the fourth century by Hypacia, the celebrated mathematician of Alexandria; but Usebe Salverte, in a memoir on this subject in the twenty-second volume of the Annales de Chimie, has shown that it was undoubtedly invented by Archimedes. This writer has given a Latin description of the instrument, from an author of great

antiquity, and from this it appears that the ancient areometer was very similar in form to the modern.

The first instance I have met with of the use of the term areometer is in the Philosophical Transactions, No. 262; in which it is applied to an instrument invented by Homberg, and employed by him in conducting some experiments on specific gravity which he has related in the Memoirs of the Academy of Sciences at Paris for the year 1699. The instrument is thus described by Dr. Davies, a writer to whom I am under great obligations for many hints of which I have availed myself in this Essay :—"It was an instrument," says the Doctor, "which Homberg had contrived and called an *areometer*, it being a large phial, to which he had adjusted a long and slender stem, whereby he could to good exactness determine specific gravities, when it was filled with equal bulks or quantities of the several fluids he proposed to examine [14]." It will, however, be perceived that this instrument is entirely on a different principle from the one now known by the name of an areometer.

The late Mr. Nicholson made a great improvement in the areometer, having adapted it to the measure of the density of solids as well as fluids. It is described in the second volume of the Manches-

[14] See *Tables of Specific Gravities*, by Richard Davies, M.D. 4to, London, 1750, page 12. For an account of an improved areometer for spirits see the *Philosophical Transactions*, No. 413, page 277, or Baddam's *Memoirs of the Royal Society*, vol. ix. page 47.

ter Memoirs, and a plate of it is given in the first volume of Nicholson's 4to Journal [15].

In France the areometer has long been in use. Those constructed by Baumé were generally employed; and as they are very frequently mentioned in the writings of the French chemists, I have deemed it advisable to explain the principle on which they were founded.

In forming this instrument he had recourse to a process similar to that of graduating the stems of thermometers from two fixed points. The first of these points was obtained by immersing the instrument in pure water. At that point of the stem which was intersected by the surface of the fluid, he marked zero, or the first of his graduation, and this commenced at or near the upper extremity of the stem.

He then provided a number of solutions of pure common salt in water: these solutions contained respectively one, two, three, four, &c. parts of the dry salt, and in each solution the quantity of water was such as to make up the weight equal to one hundred parts in the whole; so that in the solution containing one part of salt, there were ninety-nine parts of water; in the solution containing two parts of salt, there were ninety-eight parts of water, and so on with the rest. The instrument was then plunged in the first solution, in which of course it floated with a larger portion of the stem above the

[15] See *Memoirs of the Literary and Philosophical Society of Manchester*, vol. ii. page 370; and Nicholson's *Journal*, vol. i. page 110.

fluid, than when pure water was used. The fluid, by the intersection of its surface upon the stem, indicated the place for marking his first degree; the same operation repeated, with the fluid containing two pounds of salt, indicated the mark for the second degree; the solution of three pounds afforded the third degree: and in this manner his enumeration was carried as far as fifteen degrees. These first degrees applied with the compasses repeatedly along the stem, served to extend the graduation as far as was required [16]. This instrument, which is applicable to the admeasurement of densities exceeding that of pure water, is distinguished by the name of "the areometer for salts [17]."

Baumé's Areometer for Salts.

Temperature 55° Fahrenheit.

Deg.	Sp. Gr.	Deg.	Sp. Gr.
0	1.000	39	1.373
3	1.020	42	1.414
6	1.040	45	1.455
9	1.064	48	1.500
12	1.089	51	1.547
15	1.114	54	1.594
18	1.140	57	1.659
21	1.170	60	1.717
24	1.200	63	1.779
27	1.230	66	1.848
30	1.261	69	1.920
33	1.295	72	2.000
36	1.333		

[16] *Elemens de Pharmacie par M. Baumé*, fifth edition, Paris, 1784, page 410.

[17] The instrument which is at present much used by the philosophical chemists in France, is the Gravimeter of Guyton, which is said to be an improvement on Mr. Nicholson's. An ample description of it is given in Nicholson's 4to *Journal*, vol. i. page 110.

His areometer for spirits is formed upon the same principle; but in this the counterpoise is so adjusted, that most part of the stem rises above the fluid when immersed in pure water: consequently the graduations to express inferior densities are continued upwards on the stem, instead of downwards as in the former instance.

Here a solution of ten parts by weight of salt, in ninety parts of water, afforded him the first point or zero; and the mark indicated by pure water he called the tenth degree; whence by equal divisions the remaining degrees were determined [18].

BAUMÉ's Areometer for Spirits.

Temperature 55° Fahrenheit.

Deg.	Sp. Gr.	Deg.	Sp. Gr.
10 —	1.000	26 —	.892
11 —	.990	27 —	.886
12 —	.985	28 —	.880
13 —	.977	29 —	.874
14 —	.970	30 —	.867
15 —	.963	31 —	.861
16 —	.955	32 —	.856
17 —	.949	33 —	.852
18 —	.942	34 —	.847
19 —	.935	35 —	.842
20 —	.928	36 —	.837
21 —	.922	37 —	.832
22 —	.915	38 —	.827
23 —	.909	39 —	.822
24 —	.903	40 —	.817
25 —	.897		

[18] See Baumé's *Elemens de Pharmacie*, 1784, page 410; or Nicholson's 4to *Journal*, vol. i. page 37.

In Great Britain and Ireland the specific gravity of ardent spirits is determined on another principle, and various instruments, called hydrometers, have been used for the purpose. Here, unfortunately, the specific gravity is not calculated from that of water, but from the strength of an arbitrary spirit, which the Excise Board calls proof spirit, the specific gravity of which is about 0.933. The relation which all other spirituous liquors have to the standard, is expressed by saying they are so much above or under hydrometer proof.

For instance, a spirituous liquor is said to be ten per cent. over hydrometer proof, when it is so strong that one hundred gallons of it will admit an addition of ten gallons of water to reduce it to the strength of proof; and it is considered to be ten per cent. under proof, when one hundred gallons contain ten gallons of water more than is contained in proof spirits [19].

In chemical laboratories it would be inconvenient to depend solely on any instrument of the kind just described; for the range from the specific gravity of pure liquid ammonia to that of concentrated sulphuric acid is so great, that several different areometers would be required; it being almost impossible to construct a single one, on account of the great length of its stem, that could be used with convenience for every purpose.

To accommodate those persons who are particu-

[19] Speer *On the Hydrometer*, 8vo, London, 1802, page 5.

larly attached to the use of areometers, Mr. Twaddle of Glasgow fits up a box containing a series of such instruments, properly packed to prevent injury by carriage[20].

The following, however, which is the mode that is now employed in Great Britain by all philosophical chemists, may also be adopted in the laboratory of the manufacturing chemist with advantage, as it is not liable to the same errors as the areometers are, where the range is long, and that range minutely divided.

All that is necessary is to provide a convenient glass bottle with a ground conical stopper, in the side of which stopper a fine mark or indentation is to be cut with a file[21]. The weight of this bottle, with its stopper, should then be noted in grains, or a weight might be made that would always serve as a counterpoise. The bottle should then be filled with distilled water, and its weight at the temperature of 60° accurately noted down in grains. When it is filled, it will be easy to put in the stopper, because the redundant fluid will escape through the notch in the side of the stopper, and may be carefully wiped off.

For this method of preparing a gravity bottle, we are indebted to the ingenious Mr. Nicholson, who mentions it in his 8vo Chemical Dictionary, under the article Hydrometer. Unless some such con-

[20] The price of a set of Mr. Twaddle's instruments fitted up in a box 9 inches by 11 inches, is 2*l.* 12*s.* 6*d.* at Glasgow.

[21] See the plate of specific-gravity-instruments, figs. 8 and 9.

trivance be adopted, it is difficult to fill a bottle without inclosing bubbles of atmospheric air with the fluid. Where a bottle of this kind is not to be had, any phial without a stopper may be used, provided the orifice in the neck be small, and it be first ascertained what quantity of water such bottle is capable of holding.

Whenever the specific gravity of a fluid, heavier than water, is to be taken, the bottle should be filled with it, and its actual weight in grains written down: then, if this weight be divided by the weight of the water at 60°, which the bottle is known to hold, the specific gravity of the fluid in question will be accurately ascertained.

Suppose, for example, I have to find the specific gravity of a solution of carbonate of potash, and that this bottle contains exactly 1750 grains of the solution, and that the same quantity of water weighs no more than 1425 grains. Here we have only to divide the greater by the less sum, and the quotient will be found to be 1,228; for although the decimal fraction may be extended, three places will generally be sufficient for all practical purposes; and in all cases we must make the weight of the contents in water the divisor, whether the fluid to be examined be lighter or heavier than water.

In taking the specific gravity of gases or airs, it is usual to procure a glass vessel of a known capacity, and having accurately weighed it when exhausted of air, to fill it with the air or gas which is to be examined; then by weighing again, the ac-

tual weight of that volume of the aërial fluid will be determined. Thus, if the vessel should be of the capacity of 100 cubical inches, it will be found to contain $2\frac{1}{4}$ grains of hydrogen gas, or about $29\frac{1}{2}$ of azote, or $30\frac{1}{2}$ grains of atmospheric air, or $33\frac{3}{4}$ grains of oxygen gas. To weigh the gases which are produced in every operation would however be extremely troublesome. Philosophical chemists have therefore contrived to ascertain their quantities by their volumes and by subsequent references to tables of specific gravities. For this purpose slender glass jars graduated into cubic inches and tenths of an inch are now commonly employed.

It will be perceived that the methods which I have already mentioned of taking specific gravities apply only to those of *fluids:* that of solids is often attended with more difficulty.

It has been before remarked, that the specific gravity of bodies is in a direct ratio of their mass, and inversely as to their bulk. It is on the latter of these principles that the methods of taking the specific gravities of *solids* have been founded.

The usual method of taking the specific gravity of ores, metals, or other solid substances, is, by weighing them hydrostatically, that is, by comparing the difference which there is in their weights when weighed in air and in water, and to divide the absolute weight by the loss, the quotient being the specific gravity. Thus, if a mineral, which weighs three ounces in air, weighs only two ounces when immersed and weighed in water, the specific gra-

vity of such mineral is 3; that is, if water, as it generally is, be called 1.000, the substance now examined is 3.000; or, to make it still plainer, if a pint measure of water weigh *one* pound, the same bulk of the mineral will weigh *three* pounds.

There is an inconvenience attending the weighing hydrostatically from the various temperature of the water that may be used. To ensure accuracy, water of one known temperament ought always to be employed, as a variation in this respect will inevitably affect the result. A philosophical friend of mine has been in the habit of using water drawn from a deep well for such purposes, finding such water, in all seasons, to be of the same temperature, provided he employed it as soon as it came from the well. Nearly a century ago Mr. Charles Labelye, civil engineer, ascertained the specific gravity of several sorts of stone and other materials used in building. These were afterwards printed in Dodson's Calculator, 8vo, London 1747, and may even now be referred to by builders with advantage.

The works of most eminence on the subject of weighing hydrostatically were published in the following order. Medicina Hydrostatica, by the Honourable Robert Boyle, 8vo, London 1690; Sir Isaac Newton's Optics, 4to, London 1704; The Young Mathematician's Guide, by John Ward, 1706; Hydrostatical and Pneumatical Lectures, by Roger Cotes, A. M. Plumian Professor of Astronomy, &c. at Cambridge, 8vo, 1707; Hauksbee's Hydrostatical Lectures, 4to, 1710; Lectures on se-

lect Subjects in Mechanics, Hydrostatics, &c., by James Ferguson, 8vo, London 1760, together with A Supplement to this work, 4to, London 1767. A third edition of Mr. Cotes's Lectures was printed in London in 1775; in which there are some very minute and useful directions for weighing a variety of substances hydrostatically [22].

Dr. Jurin, who was Secretary to the Royal Society in the beginning of the last century, has also published some very useful remarks respecting the cautions necessary to be used in examining the specific gravity of solids, when weighed hydrostatically; for want of attending to which, several kinds of bodies, from their pores being filled with air, have appeared to be considerably lighter than they really are [23].

This method of weighing, and which can only be employed for solid bodies that are insoluble in water, is commonly conducted thus: The substance to be weighed is hung by a fine hair to one of the arms of a small scale-beam, which has a common scale-dish suspended to the other arm. When the article which is intended to be tried is suspended by the hair, it is accurately balanced by grain-weights, and the weight of it noted. It is then taken, still suspended to the arm of the balance, and immersed entirely in water, which will destroy the equilibrium, and occasion the opposite scale to

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[22] Cotes's *Hydrostatical Lectures*, page 57.
[23] *Philosophical Transactions*, No. 369.

preponderate. Weights are then taken out of the scale till the balance is restored; and the amount of the weights which it is necessary to take out to restore the equilibrium, shows the difference there is in the weight of the substance when weighed in air and in water.

When the specific gravity of a substance is required, which cannot be weighed in water, because it is soluble in that fluid, it may probably be weighed in some liquor that will not dissolve it. Thus, if it be a saline substance, it may probably be weighed with accuracy in a saturated solution of that salt.

It is obvious that, in this method of taking specific gravities, water can be employed only for such substances as are above 1.000, or denser than water; because such bodies would not sink in the water, and it is necessary that they should be completely immersed. When it is required to weigh a body hydrostatically, that is specifically lighter than water, some heavier substance must be attached to it, and its weight also must be taken into account in making the calculation.

A more ready way to determine the specific gravity of solids, when circumstances will admit of it, is to fill a phial with water, and note the weight of the whole accurately in grains. Then weigh 100 grains of the substance to be examined, and drop it gradually into the phial of water. The difference of weight of the bottle with its contents now, and when it was filled with water only, will give the spe-

cific gravity of the matter under consideration. For example, if the bottle weighs 50 grains more than it did when it was filled with water only, it shows that 100 grains of the mineral displace only 50 grains of water, and consequently that it is twice the specific gravity of water.

It was on this principle that Archimedes is said to have discovered the deceit which had been practised upon his relative Hiero the Second, king of Syracuse, by an unprincipled goldsmith who had been employed to fabricate a crown of pure gold for him, as an offering to the gods.

The workman, it seems, had alloyed the crown with a portion of silver, imagining that the fraud could not be detected;—but Archimedes, suspecting that a cheat had been practised, hit upon the following method of ascertaining the fact:

He made two masses, each of equal weight with the crown, one of gold and the other of silver: when he had done this, he filled a large vessel to the brim with water, and put the silver mass into it, upon which a quantity of water overflowed, equal to the bulk of the mass: then taking the metal out, he filled up the vessel again, measuring the water exactly which he put in: this showed him what measure of water answered to a certain quantity of silver.

He then tried the gold in like manner, and found that it caused a less quantity of water to overflow; the gold being less in bulk than the silver, though of the same weight. Having filled the vessel a

In the mixture of crude platinum with silver, it is well known that there is a diminution of specific gravity; and in its mixture with iron, an increase. Tin is specifically much lighter than copper, yet the specific gravity of the compound, bell-metal, is greater than that of copper itself[27]. From inattention to such facts many deceptions might arise, and innumerable errors be committed.

Mr. Scheffer made out a table for determining the quantities of lead and tin in any given mixtures of the two, by taking the specific gravity of the alloy; and this was published in the Swedish Acts for 1755. But as this table was formed without comparison with standard mixtures, it cannot be depended upon, and is consequently of no value.

Having thus shown that the specific gravity of a compound metal can never, with any certainty, be deduced by calculation from that of its mixture with another metal, as a dilatation or contraction of the volume results from their mutual action on each other; it may be observed that just so is it with the *melting* point of a compound metal. Tin melts at 413° of Fahrenheit, bismuth at 476°, and lead at about 612°; but a certain mixture may be made with these metals, that will fuse at the temperature of 202°. There are also some curious anomalies in the melting points of various mixtures of lead and tin.—See my *Tables of the melting points of*

[27] Lewis's *Phil. Commerce of the Arts*, page 555; and his Notes to Neumann, vol. i. page 97.

various metallic Compounds in the Essay on Edge-tools.

The goodness of tin may be generally known by its specific gravity, though it would be erroneous to judge of the ores of tin by the same means, because some specimens of the best ores are of a specific gravity greater even than that of the pure metal itself[28].

A deception equally great would arise from an attempt to calculate the proportions of many of the mixtures of liquid substances, without having made previous experiments to determine the amount of their condensation by mixture: for, when two liquids unite chemically, the compound has generally a density greater than the mean density.

If we make a mixture of ardent spirit with water, the specific gravity of the mixture will not be a mean specific gravity. Water itself is of far greater gravity than the oxygen and hydrogen gas which compose it. One measure of sulphuric acid and one measure of water, when mixed, will not occupy the space of two measures; consequently the mixture cannot have a specific gravity corresponding to the mean between those of the two original fluids. This has been mathematically demonstrated by Dr. Ure in his Dictionary of Chemistry, to which I refer the reader.

It will be remembered, therefore, that to ascertain the specific gravity of a body may serve to fur-

[28] Lewis's Notes to Caspar Neumann's Chemistry, vol. i. page 131.

nish some idea of its purity, some substances being increased, and others diminished, in their specific gravities, by sophistication; that it will indicate the comparative value of certain metallic, acidulous or alkaline solutions, and has innumerable other uses in the hands of the manufacturing or philosophical chemist, some of which have been mentioned at pages 205 and 206: it does not, however, afford any means of accurately discovering the amount of adulteration, or establishing a proof of the quantities of the components, whether the mixture be fluid or solid.

A method of calculating the mean specific gravity of a compound from those of its component parts has been lately published by Dr. Ure in his Chemical Dictionary before mentioned under the article Specific Gravity; and in the Journal of Science and the Arts, vol. iv. page 151.

Nothing now remains but to notice a distinct method of taking the specific gravity of fluids, which differs in some respects from those already described, and is that which I have adopted in my own Chemical Manufactory for many years past.

This ingenious contrivance, which originated with Dr. Lewis, was communicated to me by the amiable Mr. Samuel Moore, late Secretary to the Society for the Promotion of Arts, Manufactures and Commerce, who favoured me with a sight of Dr. Lewis's manuscript, and allowed me to make such extracts from it as I conceived might be useful.

In this scheme the specific gravity of a liquor is

estimated from the excess of the weight of a certain measure of it, above that of an equal measure of distilled water. For this purpose, a peculiar set of weights, which he called CARATS, is to be made in the following manner:—

A convenient bottle, with a long narrow neck [99], being procured, the tare of the bottle is first taken, and a weight made corresponding thereto, as the exact counterpoise: it is then to be completely filled with distilled water at 60°, or till the water rise to a mark made in such part of the neck as shall be found most convenient. A weight corresponding to the net weight of this water is then to be made, and marked 128; after which this weight is to be accurately divided into two equal parts, and a weight made equal to one of these parts is to be marked 64. By continuing the subdivision we shall have the weights 32, 16, 8, 4, 2, 1, carats; so that each carat, though in some measure of an arbitrary value, must be one hundred and twenty-eighth of the water required to fill such bottle.

When these weights are adjusted, it will be proper to make another counterpoise besides that already described for the tare of the bottle, and this must be an exact balance to both the water and bottle. We then make our estimate in this way: So many carats as the bottle when filled with any other fluid, exceeds this united weight or *counterpoise*, so many carats strong is such fluid to be estimated.

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[99] See the plate of specific gravity, fig. 10.

This small apparatus is equally useful for taking the specific gravities of alcohol, ether, liquid ammonia, oils, or any other fluid body which is *lighter* than water. In such cases, the only variation necessary is to put the carat-weights in the scale with the bottle, instead of putting them with the water-poise; and whatever number of carats may be required for bringing the bottle and the water-poise to an equilibrium, so many carats is the fluid lighter than an equal measure of pure water; and as the perfection of these liquids is in a direct ratio with their levity, their true value is at once demonstrated.

Soon after I had printed this account of my apparatus for taking the specific gravity of fluids, Mr. Gill informed me that he had formed an apparatus which may be considered to be in some measure an improvement upon mine; and which he thus describes: He has a phial as usual, with a ground glass stopper, having a groove cut upon it to let the air and superfluous fluid escape on closing the orifice. The weights are contained in a metallic box, the lid of which is made to be exactly equal in weight to the empty glass bottle with its stopper, whilst the other part of the box (weighing 128 carats) is equal to the weight of the distilled water which the bottle at a certain temperature is capable of containing. His weights consist of one of 64 carats, one of 32, one of 16, one of 8, one of 4, one of 2, and two weights of 1 carat each. The last two are of the same denomination, in order that the amount of the whole may be equal to 128, without which the specific gra-

vity of a fluid equal to 2000 could not be obtained. He has also weights for the half, fourth, eighth, and sixteenth of a carat.

The following is a table of carats, with their corresponding degrees of specific gravities, which I constructed many years ago for the use of my own laboratory.

A Table of Carats, with their corresponding Degrees of Specific Gravities, for ascertaining the Specific Gravities of Fluids heavier than Water.

Carats.	Sp. Gr.	Carats.	Sp. Gr.
1 =	1.0078	23 =	1.1796
2	1.0156	24	1.1875
3	1.0234	25	1.1953
4	1.0312	26	1.2031
5	1.0390	27	1.2109
6	1.0468	28	1.2187
7	1.0546	29	1.2265
8	1.0625	30	1.2343
9	1.0703	31	1.2421
10	1.0781	32	1.2500
11	1.0859	33	1.2578
12	1.0937	34	1.2656
13	1.1015	35	1.2734
14	1.1093	36	1.2812
15	1.1171	37	1.2890
16	1.1250	38	1.2968
17	1.1328	39	1.3046
18	1.1406	40	1.3125
19	1.1484	41	1.3203
20	1.1562	42	1.3281
21	1.1640	43	1.3359
22	1.1718	44	1.3437

Carats.	Sp. Gr.	Carats.	Sp. Gr.
45 =	1.3515	82 =	1.6406
46	1.3593	83	1.6484
47	1.3671	84	1.6562
48	1.3750	85	1.6640
49	1.3828	86	1.6718
50	1.3906	87	1.6796
51	1.3984	88	1.6875
52	1.4062	89	1.6953
53	1.4140	90	1.7031
54	1.4218	91	1.7109
55	1.4296	92	1.7187
56	1.4375	93	1.7265
57	1.4453	94	1.7343
58	1.4531	95	1.7421
59	1.4609	96	1.7500
60	1.4687	97	1.7578
61	1.4765	98	1.7656
62	1.4843	99	1.7734
63	1.4921	100	1.7821
64	1.5000	101	1.7890
65	1.5078	102	1.7968
66	1.5156	103	1.8046
67	1.5234	104	1.8124
68	1.5312	105	1.8202
69	1.5390	106	1.8280
70	1.5468	107	1.8358
71	1.5546	108	1.8436
72	1.5625	109	1.8514
73	1.5703	110	1.8593
74	1.5781	111	1.8671
75	1.5859	112	1.8750
76	1.5937	113	1.8828
77	1.6015	114	1.8906
78	1.6093	115	1.8984
79	1.6171	116	1.9062
80	1.6250	117	1.9140
81	1.6328	118	1.9218

Carats.	Sp. Gr.	Carats.	Sp. Gr.
119 =	1.9296	124 =	1.9687
120	1.9375	125	1.9765
121	1.9453	126	1.9843
122	1.9531	127	1.9921
123	1.9609	128	2.0000

Mr. Gill's Table of Carats for Fluids *lighter* than Water.

Carats.	Sp. Gr.	Carats.	Sp. Gr.
1 =	0.9922	27 =	0.7891
2	9844	28	7813
3	9766	29	7735
4	9688	30	7657
5	9610	31	7579
6	9532	32	7501
7	9454	33	7422
8	9376	34	7344
9	9297	35	7266
10	9219	36	7188
11	9141	37	7110
12	9063	38	7032
13	8985	39	6954
14	8907	40	6876
15	8829	41	6797
16	8751	42	6719
17	8672	43	6641
18	8594	44	6563
19	8516	45	6485
20	8438	46	6407
21	8360	47	6329
22	8282	48	6251
23	8204	49	6172
24	8126	50	6094
25	8047	51	6016
26	7969	52	5938

Carats.	Sp. Gr.	Carats.	Sp. Gr.
53	= 0.5860	91	= 0.2891
54	5782	92	2813
55	5704	93	2735
56	5626	94	2657
57	5547	95	2579
58	5469	96	2501
59	5391	97	2422
60	5313	98	2344
61	5235	99	2266
62	5157	100	2188
63	5079	101	2110
64	5001	102	2032
65	4922	103	1954
66	4844	104	1876
67	4766	105	1797
68	4688	106	1719
69	4610	107	1641
70	4532	108	1563
71	4454	109	1485
72	4376	110	1407
73	4297	111	1329
74	4219	112	1251
75	4141	113	1172
76	4063	114	1094
77	3985	115	1016
78	3907	116	0938
79	3829	117	0860
80	3751	118	0782
81	3672	119	0704
82	3594	120	0626
83	3516	121	0547
84	3438	122	0469
85	3360	123	0391
86	3282	124	0313
87	3204	125	0235
88	3126	126	0157
89	3047	127	0079
90	2969	128	0001

For those persons who have been in the habit of calculating specific gravities by the wine-pint, or, to speak more accurately, by a measure holding exactly sixteen avoirdupois ounces of water, as also for those who may not be conversant with the mode of reckoning specific gravities by decimal arithmetic, I subjoin the following table. We know it has been decided that the wine-pint holds rather more than sixteen ounces of water; but it is most convenient for all *common* purposes, still to consider it as a measure of sixteen ounces, and this table is constructed accordingly.

A Table of Carats, with their correspondent Weights of the Wine-pint, in Ounces and Drachms Avoirdupois.

Carats.	Oz.	Dms.	Carats.	Oz.	Dms.
1 =	16	2	19 =	18	6
2	16	4	20	18	8
3	16	6	21	18	10
4	16	8	22	18	12
5	16	10	23	18	14
6	16	12	24	19	0
7	16	14	25	19	2
8	17	0	26	19	4
9	17	2	27	19	6
10	17	4	28	19	8
11	17	6	29	19	10
12	17	8	30	19	12
13	17	10	31	19	14
14	17	12	32	20	0
15	17	14	33	20	2
16	18	0	34	20	4
17	18	2	35	20	6
18	18	4	36	20	8

Carats.	Oz.	Dms.	Carats.	Oz.	Dms.
37 =	20	10	74 =	25	4
38	20	12	75	25	6
39	20	14	76	25	8
40	21	0	77	25	10
41	21	2	78	25	12
42	21	4	79	25	14
43	21	6	80	26	0
44	21	8	81	26	2
45	21	10	82	26	4
46	21	12	83	26	6
47	21	14	84	26	8
48	22	0	85	26	10
49	22	2	86	26	12
50	22	4	87	26	14
51	22	6	88	27	0
52	22	8	89	27	2
53	22	10	90	27	4
54	22	12	91	27	6
55	22	14	92	27	8
56	23	0	93	27	10
57	23	2	94	27	12
58	23	4	95	27	14
59	23	6	96	28	0
60	23	8	97	28	2
61	23	10	98	28	4
62	23	12	99	28	6
63	23	14	100	28	8
64	24	0	101	28	10
65	24	2	102	28	12
66	24	4	103	28	14
67	24	6	104	29	0
68	24	8	105	29	2
69	24	10	106	29	4
70	24	12	107	29	6
71	24	14	108	29	8
72	25	0	109	29	10
73	25	2	110	29	12

Carats.	Oz.	Dms.	Carats.	Oz.	Dms.
111 =	29	14	120	31	0
112	30	0	121	31	2
113	30	2	122	31	4
114	30	4	123	31	6
115	30	6	124	31	8
116	30	8	125	31	10
117	30	10	126	31	12
118	30	12	127	31	14
119	30	14	128	32	0

Once more, I must inculcate the necessity of attending to the degree of temperature of the atmosphere when the experiment is made, as well as to that of the material to be examined, when its temperature is raised, or diminished, so as to deviate from the former; for we know that the specific gravity of all bodies is greatly influenced by sensible caloric, and their bulk increased or diminished in proportion to the quantity they contain. I repeat, that it is of little avail to ascertain the specific gravity of bodies, if proper attention be not at the same time paid to their degree of temperature; for gases, fluids, and solids, vary in bulk according to the quantity of free caloric contained in them [30].

[30] For an account of the expansion of the gases by heat consult Dalton's *New System of Chemical Philosophy*, part 1. Manchester 1808. A table of the expansion of glass is given by Dr. Henry in his *Elements of Experimental Chemistry*, vol. ii. page 524; and Mr. John Ellicott published "The description and manner of using an instrument for measuring the degrees of the expansion of metals by heat," in the *Philosophical Transactions*, No. 443, page 297. A collection of facts respecting the expansion of wood by heat will be found in a memoir by Dr. Rittenhouse, published in the *Transactions of the American Philosophical Society*.

Mr. Nicholson has stated, that he finds by experiment that the fifth decimal figure changes in *water* at every three degrees of Fahrenheit's thermometer. Other fluids will undoubtedly observe a different ratio; but a manufacturer, to whom it is often necessary to try the specific gravity of one particular liquor, might, for his own use, easily form a table of these variations.

In chemical manufactories it is often necessary to take the specific gravity of a fluid when nearly at a boiling heat. To do this, I have always employed a *stone* bottle of a determinate size, because this ware will endure such a temperature without breaking. I have thought of glass bulbs: but if one of these small instruments be selected which will just swim in a fluid of the specific gravity I want, the same would also swim on a liquor of greater specific gravity, and this might occasion an error of some importance. In like manner, a bulb might be chosen that would just sink in a liquor of a determinate specific gravity, but it would also sink in a lighter fluid, and this might equally produce deception. Mr. London, who has obtained a patent for purifying muriate of soda (rock-salt), has, however, adopted the ingenious expedient of employing *two* bulbs of different weights at once, and by this means he readily determines when his saline liquor is evaporated to the point which is necessary for his purpose. For, if the lixivium be too much diluted, both these bulbs will fall to the bottom; and if it be too heavy, both of them will

swim: but when he perceives that the heaviest of these falls and the other swims, he then knows that he may rely upon the liquor being of the medium specific gravity which he requires.

When I spoke of the necessity of using the thermometer in taking specific gravities, it was my intention to observe, that the important instrument which is generally employed in Great Britain was constructed by Mr. Gabriel Daniel Fahrenheit, a native of Hamburgh, who came to this country in the year 1724, was elected a fellow of the Royal Society of London, and in that year published "A Dissertation on Thermometers." I state these circumstances merely to give me an opportunity of mentioning, that this gentleman was also concerned in investigating the specific gravities of various bodies, and that while in England he published "A Table of the specific Gravities of twenty-eight several Substances," with various observations, in the Philosophical Transactions, No. 283. If any of my readers should know of a memoir, or an engraved portrait, of this eminent man, I shall most thankfully receive such information. There is no notice of him or of his portrait either in Bromley, Grainger, or Noble, all of which I have carefully examined.

The metals afford the greatest variety in their specific gravities of any order of substances in nature. The following table, which gives a view of the principal ones arranged according to their spe-

cific gravities, I have thought might be useful, and suitable for admission into this Essay.

A TABLE
OF
THE SPECIFIC GRAVITY OF THE METALS.

Platinum	21.470
Gold	19.300
Tungsten	17.400
Mercury, frozen	14.465
Ditto, fluid	13.568
Palladium	11.500
Lead	11.350
Rhodium	10.649
Silver	10.474
Bismuth	9.822
Copper	8.735
Cobalt	8.700
Molybdenum	8.611
Nickel	8.380
Uranium	8.100
Manganese	8.043
Iron	7.700
Tin	7.291
Zinc, hammered	7.190
Do. cast in bars	6.861
Antimony	6.712
Tellurium	6.115
Chromium	5.900
Arsenic	5.763
Sodium	0.972
Potassium	0.865

ESSAY IV.

ON

CALICO-PRINTING.

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ON

CALICO-PRINTING.

CALICO-PRINTING is an art of very considerable importance to this country; it has proved the source of immense wealth to many individuals, and for several years past has brought a great revenue to the state. Notwithstanding its value and national consequence, the majority even of well-informed people know little or nothing of the processes by which this peculiar manufacture is conducted.

This ignorance will appear the more remarkable, when it is considered that linens were fabricated, and the arts of dyeing and staining garments, something like the present calico-printing, were known and practised in the earliest ages of which history gives us any detail.

Hence it may very fairly be presumed that a faithful account of the nature of this business would

be very acceptable to the public, and that, in the course of the narration, if any improvements on the present practice should be suggested, it is possible that such an account may not, even to the calico-printer himself, be totally uninteresting and useless. We shall begin with an attempt to trace the history of the art, and of its progress towards that perfection to which it has now attained.

In the time of Moses the land was employed for the growth of flax[1] as well as of corn; and that this flax was used for the fabrication of cloth, may be collected from a variety of circumstances, especially from an examination of some Egyptian mummies, the most ancient of which (at least such as have been brought to Europe) are bound round with folds of linen similar to the flaxen cloth of the present day.

There is a paper of Dr. Hadley, in the fifty-fourth volume of the Philosophical Transactions, giving an account of the examination of an Egyptian mummy, in the presence of several of the Fellows of the Royal Society. After describing its general appearance, he says, "The outward painted covering being removed, nothing but linen fillets were to be seen, which inclosed the whole mummy. The uppermost fillets were of a degree of fineness nearly equal to what is now sold in the shops under the name of long lawn, and were woven something after the manner of Russian sheeting." This

[1] See *Exodus* ix. 31.

mummy was taken from a catacomb near Cairo; and when the age of these catacombs is considered, it gives great antiquity to the art of weaving fine linen.

We have evidence, however, that the invention of weaving is still more ancient than even the times when the embalming of the Egyptian mummies was in vogue. This is evident from the answer which Abram gave to the King of Sodom:—"I will not," said he, "take from a thread of the woof, even to a shoe-latchet, lest thou shouldest say, I have made Abram rich[2]."

Moses informs us that Abimelech made a present of a veil to Sarah[3]. He observes also, that Rebecca covered herself with a veil, when she perceived Isaac[4]; and that Pharaoh arrayed Joseph in a vesture of fine linen or cotton, when he made him viceroy of Egypt[5]. A weaver's shuttle is also mentioned in the book of Job[6]. These facts incontrovertibly prove the great antiquity of the art of weaving with warp and woof.

In these very ancient times this work was performed in a standing posture[7]. Both Homer[8] and Virgil[9] attest this. This was owing to the construction of their looms, in which the warp was extended perpendicularly from top to bottom, and kept firm

[2] See *Genesis* xiv. 23. [3] *Ibid.* xx. 16. [4] *Ibid.* xxiv. 65.
[5] "And Pharaoh took off his ring from his hand, and put it upon Joseph's hand, and arrayed him in vestures of fine linen." *Genesis* xli. 42. [6] *Book of Job*, chap. vii. ver. 6.
[7] Junius *de Pictura Veter.* lib. i. cap. 4. p. 26.
[8] *Iliad.* i. ver. 31. [9] *Georgic.* lib. i. ver. 294.

by means of a piece of wood, to which they hung very heavy weights[10].

" Inventress of the woof, fair Lina flings
The flying shuttle through the dancing strings,
Inlays the broider'd weft with flowery dyes,
Quick beat the reeds, the pedals fall and rise;
Slow from the beam the lengths of warp unwind,
And dance and nod the massy weights behind."

Five hundred years after the death of Moses, and nearly a thousand years before Christ, it is related that Solomon imported linen yarn from Egypt[11]: and after this period the city of Tyre is represented as abounding in fine linen; for, when Ezekiel is describing the grandeur of that city, and the opulence of her merchants, he says: " They have made all thy ship-boards of fir trees of Senir; they have taken cedars from Lebanon to make masts for thee; FINE LINEN with broidered work from Egypt, was that which thou spreadest forth to be thy sail[12]."

From the manner in which this is introduced, it is evident that the writer considered fine linen to be an article of great rarity. In his days *matting* was commonly used for sails; hence sails of *linen* must have been thought extremely magnificent. " The sails of the ancient Phœnicians were made of diffe-

[10] Goguet's *Origin of Laws*, &c. vol. i. 126.

[11] "And Solomon had horses and linen yarn brought out of Egypt; the king's merchants received the linen yarn at a price." 1 *Kings* x. 28.

[12] *Ezekiel* xxvii. 7.

rent substances, such as hemp, rushes, long-leaved plants, mats, and skins.—Yet those of the Greeks at the same period were most commonly of cloth[13]." Sails of matting are still used on the vessels navigated by the Arabs on the Red Sea. We are entitled however, from this body of concurrent testimony to conclude, that linen cloth has been in use, though perhaps not very commonly, from the time of Moses to the present day.

On the other hand we have the positive evidence of Pliny, that in his time there were many ancient families at Rome, who boasted of never having admitted linen cloth into their houses, considering the use of it as a mark of great and criminal effeminacy[14].

Pliny says also, that "Lentulus Spinter was the first man who in the games drew fine curtains over the great amphitheatre of Rome; and that not long after this, Cæsar Dictator caused the high fair street called *Sacra* to be hung on both sides from his own dwelling-house to the very Capitol; which magnificent and sumptuous sight was much wondered at, and seen with great admiration." He adds, that "Alexander the Great was the first person who had sails or linen flags that were dyed with *colours*, that he borrowed it from the Indians, and that afterwards a red purple banner erected on the top of the mast was the badge of the royal admiral's ship."—Holland's Pliny, vol. ii. page 5.

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[13] Goguet's *Origin of Laws, &c.*, vol. ii. page 326.
[14] Plin. *Hist. Nat.* lib. ix. c. 1.

Some of the Roman emperors, however, were so desirous of having their subjects instructed in the manufactory of it, that they formed colleges in various parts of their home and foreign dominions, for teaching the art of weaving linen cloth. One of these imperial manufactories was established at *Venta Belgarum*, the site of the present city of Winchester [15].

Equally decisive is the testimony of history respecting the antiquity of *coloured* linens, which appear to have been known almost in the very earliest ages.

More than three thousand years ago, a shrewd matron tied a *scarlet* thread round the hand of one of Tamar's children [16]; and Homer, who flourished nine hundred years before Christ, speaks of the variegated cloths of Sidon as very magnificent productions [17]. Jacob made for Joseph a coat of many colours, which was probably of linen, or of cotton [18]; and some hundred years afterwards we read of Solomon sending to Tyre for coloured linens, and of the king of that country answering his request, by furnishing him with "a man skilful to work in gold and in silver; in brass, in iron, in stone, and in timber; in purple, in blue, in *fine linen* [19], and in crimson.

The books of the Pentateuch frequently mention the ornaments for the Tabernacle, as composed of

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[15] Cambden's *Britannia*, vol. i. page 139.
[16] *Genesis* xxxviii. 27.
[17] *Iliad.* lib. vi. line 289.
[18] *Genesis* xxxvii. 3.
[19] 2 *Chronicles* ii. 14.

blue and purple and scarlet and fine linen; and it has been remarked by Mr. Delaval[20], that in those ancient writings these colours are constantly arranged exactly in the same order[21], and that this order is the true prismatic series of those colours.

This is certainly a very striking fact; and it is also not a little curious, that after a lapse of several centuries which intervened between the period described in Exodus and the time of Solomon, the colours employed in the Temple ornaments should be still mentioned in the same order as those of the Tabernacle had been formerly noticed; which is exactly the case, excepting in one single instance, where the red is called *crimson* instead of scarlet[22].

May not this very interesting fact be considered as an internal proof of the antiquity of the sacred writings? We know how much mankind have at all times been addicted to the practice of imitating Nature; and next to the great luminary of our system, the rainbow was surely the grandest object which the writers of these early books had ever beheld.

I must not, however, forget that I shall be expected to give some account of the progress of the art of staining, painting, or printing linen and calico.

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[20] See Delaval's *Experimental Inquiry into the Cause of the Change of Colours in opake and coloured Bodies.*

[21] See *Exodus* xxv. 4. xxvi. 1. 31. 36. xxvii. 16. xxviii. 6. 8. 15. xxxv. 6. 23. 25. 35. xxxvi. 8. 35. 37. xxxviii. 23. xxxix. 1—29, and several other places.

[22] 2 *Chronicles* iii. 14.

An historian who wrote more than four hundred years before the commencement of the Christian æra, when describing the nations which inhabited Caucasus, a mountain extending throughout the region of Georgia and Armenia, affirms that by means of vegetables ground and diluted with water, these people adorned their cloth with the figures of various animals, and that the dyes were permanent which were thus obtained [23].

Valerius Flaccus, an historian who wrote in the age immediately succeeding that of Christ, distinguishes a warrior slain at Colchis, during the Argonautic expedition, by a *painted* garment [24], and at the same time specifies that his dress was of fine white linen [25].

That dyeing materials were, in ancient times, plentifully produced at Colchis and Tournefort, is well known; and according to Mr. Delaval, great quantities of these materials are still used in the very same species of dyeing. Besides, more than two thousand camel loads of madder are annually

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[23] "Le Caucase est habité par plusieurs nations différentes. "On assure que ces peuples ont chez eux une sorte d'arbres dont les feuilles broyées et mêlées avec de l'eau fournissent une couleur avec laquelle ils peignent sur leurs habits des figures d'animaux. L'eau n'efface pas ces figures—et, comme si elles avaient été tissues, elles ne s'usent qu'avec l'étoffe." Larcher's *Translation of Herodotus*, i. 203.

[24] "Cadit . . . . . Taulantis alumnus . . .
Tenuia non illum candentis carbasa lini,
Non auro depicta chlamys, non flava galeri
Cæsaries, pictoque juvant subtemine bracæ."
VALERIUS FLACCUS, vi. 221 et seq.

sent from Georgia to Diurbeck and India, where the finest calicoes are still printed or painted with it [26].

Strabo, the Greek philosopher, who was contemporary with our Saviour, relates that the Indians wore flowered linens [27], and that India abounded with drugs, roots, and colouring substances, from which some very beautiful dyes were produced [28]; and we know that the inhabitants of India used a purple and scarlet dye, resembling cochineal in colour, and in the manner of its production.

Moreover, the statues of Isis, which formerly were so abundant in Egypt, were generally adorned with *parti-coloured* cloths, which, as has been remarked, must have been of linen, or of cotton [29], because woollen was so much abhorred by the Egyptians that the lowest of the people would neither use it [30] nor allow it to be employed even in their interments. Such indeed was their aversion, that it extended to the flocks, and to the very shepherds themselves who attended them. "Every shepherd," says the writer of the Pentateuch, "is an abomination unto the Egyptians [31]."

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[25] Pliny says, that in his time the finest cloth was made from the cotton plant, which grew in India and in Persia, lib. xii. cap. 10.

[26] Delaval, page xxi. [27] Strabo, lib. xv. p. 709.

[28] Strabo, lib. xv. p. 694—699 *de India*. [29] Delaval, p. 34.

[30] "And it shall come to pass, that when they enter in at the gates of the inner court, they shall be clothed with linen garments, and no wool shall come upon them." *Ezekiel* xliv. 17.

[31] *Genesis* xlvi. 34.

The methods which the Egyptians adopted to produce these parti-coloured linens is very particularly described by the Elder Pliny, who perished by an eruption of Vesuvius in the year 79 of the Christian æra. "The Egyptians," says he, "began by painting, or drawing, on white cloths with certain drugs, which in themselves possessed no colour, but had the property of attracting or absorbing colouring matters. After which, these cloths were immersed in a heated dyeing liquor; and though they were colourless before, and though this dyeing liquor was of one equable and uniform colour, yet when taken out of it soon afterwards they were found to be wonderfully tinged of different colours, according to the peculiar natures of the several drugs which had been applied to their respective parts; and that these colours could not be afterwards discharged by washing[32].

The agreement which there is between this account of the management of the ancients and the present practice, cannot fail to strike any one who is at all conversant with the processes now in use.

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[32] See Pliny, lib. xxxv. cap. 11. § 42; and Bancroft *On Permanent Colours*, vol. i. p. 170. Goguet's *Origin of Laws*, vol. i. page 105.

[33] Lib. xxxi. cap. 10. Potash is the article generally employed at this time by the English, though some printers use soda.

[34] Strabo, lib. xvi. page 757.

[35] "The Phœnicians (says Campbell) were the first who moulded commerce into a science, and framed to themselves the glorious design of making mankind known and useful to each other. They knew that all countries were rich by nature, or

And from this relation, and other testimony still on record, there can be no doubt but that these people employed both iron and alum as mordants, though these mordants might not be prepared exactly in the same way, or in so effective a manner, as they are by the moderns.

Native soda, which abounded in Egypt, was also known to the ancients; and we have the direct assurance of Pliny that the dyers of antiquity were in the habit of using it in their processes [33].

But amongst the countries of the East which practised dyeing, the Phœnicians were the most celebrated, and particularly for their purple colour. So great was the demand for this article, that the city of Tyre grew to a vast extent, from the number of workmen employed in its manufacture; and it was from a sense of the great national utility of their purple dye, that the Phœnicians attributed its invention, which was the principal foundation of their trade and wealth, to the gods [34].

It is also well known, that the Phœnicians visited Britain [35] at a very early period of history [36]; and that

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might be made so by industry and art; and therefore they did not only visit remote regions for what they could bring away, or obtain from the barbarous inhabitants for gewgaws and trifles, but they endeavoured to propagate sense, civility, and the art of living; and, in short, wherever they came, sought to make the people as wise and as industrious as themselves." Campbell's *Political Survey of Great Britain*, vol. i. page 24.

[36] "The first nation which visited this island on account of trade, was unquestionably the Phœnicians. This is positively affirmed by Strabo, and acknowledged by many other authors." Henry's *History of Great Britain*, 8vo, vol. ii. page 199.

Tin was an object of merchandize with these people, we have the positive testimony of a writer who flourished 600 years before Christ. In describing the riches and consequence of Tyre, one of the chief cities of Phœnicia, he says, "With silver, iron, TIN, and lead, they traded in thy fairs[37]." Can there then be any doubt but that the tin which they took from this island was used by them in dyeing? for we know that this metal is absolutely necessary to the production of certain red colours, whether the materials from which the colouring matter is produced be of animal or vegetable origin. Indeed, according to Pliny, the vats themselves in which the Tyrian dye was made, were of tin[38], the very best possible material for the purpose, and that which the opulent dyers in this country now employ. It is well known that the majority of the English dyeing-vessels are of copper; but those who are curious in their colours, particularly the large woollen-dyers, invariably have them of tin. Some of these pans weigh more than two tons, and cost from 300*l.* to 500*l.* each. Mr. Boyle, 130 years ago, discovered that a bright scarlet was never produced unless *tin* vessels were employed[39].

Besides the purple which was thus prepared at Tyre and other parts of Syria, the ancient inhabitants of India were also in the habit of using a purple and scarlet dye, which they procured from the cochineal insect, or from some other insect resembling it.

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[37] *Ezeziel* xxvii. 12. [38] Pliny, lib. ix. cap. 38.
[39] *Experimenta de Coloribus*, 4to, 1680.

For Ctesias, who flourished about four hundred years before Christ, and was a great favourite at the court of Persia, and Ælian the philosopher, who taught rhetoric at Rome in the reign of Alexander Severus, both give an account of the insects which yielded it, and of the plants on which they fed. We also learn that so large a quantity of this colouring matter was produced in India, as to become an article of export in those early times. It is probable, therefore, that it was by means of this insect, whatever it might be, that these Asiatics were supplied with that abundance of purple, which enabled even the lowest ranks among them to wear clothes of that colour [40].

There can indeed be little doubt but that the true cochineal was known in Persia very early. The king of Persia, we are told, sent to the emperor Aurelian, among other things of value, some woollen cloth which was of a much brighter purple than any that had ever been seen in the Roman empire, and in comparison of which all the other purple cloth worn by the emperor and the ladies of the court appeared dull and faded [41].

From various accounts it appears, that formerly, in India, the cotton cloths, when brought from the weavers, partly bleached, were worn next to the skin, by the dyer and by all his family, during the space of eight or ten days. These cottons could not however have been of a length equal to the pieces

[40] See Delaval's preface, page 24.

[41] Beckman, from Vopiscus in *Vita Aureliani*, cap. 29.

of the present day; they were probably nothing but the mere shawls, which have been common in India from time immemorial. Among the magnificent dresses of the present Asiatics, there is nothing more esteemed than shawls of various colours, and these are frequently given to the great by way of present [42].

When the cloth had been thus worn until it was thoroughly soiled, the several pieces underwent repeated macerations in water, with goats' dung, and were afterwards submitted to frequent washings and to as frequent dryings in the rays of an intense sunshine. Afterwards, they were soaked for some time in the mixture of the astringent fruit of the yellow *myrobalans*, and of curdled buffalo's milk. When thoroughly impregnated therewith, they were squeezed, dried by exposure to the sun, and then, by pressure and friction, they were made smooth enough for being drawn upon by the pencil, with the different mordants.

The first of these mordants was an iron liquor, made by dissolving iron in a mixture of sour palm wine and rice-water, or water in which rice had been boiled for a considerable time. This liquor was applied to the figures or spots intended to become black, and afterwards the aluminous mordant was applied, commonly by children, with the pencil, to the parts intended to be made red. The pieces

[42] Irwin's *Travels up the Red Sea*, pages 60, 189, 272, 285. Dr. Clark's *Harmer*, vol. iv. 256.

were then exposed to the hottest sunshine, that the parts to which the mordants had been applied might be dried as much as possible; and then they were thoroughly soaked in pits of water, to cleanse them from the superfluous mordants, as well as from the buffalo's milk, &c.; and lastly they were dyed in water, with certain roots answering nearly in their effects to those of madder [43].

It was in this way the manufacture of printed cottons was conducted by the Indians in *former* times. The following is an account of the *modern* practice, in one particular branch of their manufacture, which I procured from a gentleman who has spent some time in India, and which I now subjoin, rather for the amusement than the instruction of the British calico-printer.

The finest cotton chintz counterpanes, says he, which the natives call pallampoors, are manufactured at Madras. These are woven in one piece, from two to four yards square, and are printed, or rather painted, with various designs, and in various colours. Their method is to draw the pattern first on sheets of paper sewn together, of the size of the intended pallampoor; and then to prick out the same in the paper with a sharp instrument. When this is done, the paper pattern is smoothly fixed upon the cloth, which is previously damped, and

[43] Most of these particulars were published by Father Cœurdoux, a missionary at Pondicherry, in the twenty-sixth volume of "*Recueil des Lettres Curieuses et Edifiantes, &c.*" See also Bancroft *On Permanent Colours*, page 172.

then a small muslin bag containing some kind of black powder is rubbed over the whole, in order to pass a part of the powder through the pin-holes, and completely mark out the pattern.

The pattern being thus sketched upon the cloth, the paper is removed; and when the outline of the various figures is drawn with a pencil, the piece is considered to be ready for receiving the colours.

One colour is then laid on with a brush made with a tough root of a particular kind of tree, or with the husk of the cocoa nut; and when this is dry, the piece of cotton is given to a woman to wear, or to use in the family, till it be very much dirtied; in order that it might necessarily undergo a thorough washing, which is thought requisite to prove the goodness and permanency of the colour. Another colour is then laid on in the same manner, and the piece is again submitted to the same trial of wearing and washing. The Asiatics may not be aware of it; but doubtless the long exposure to the air in these cases, is the important point, as it is well known that the atmosphere is a prime agent in rendering many colours permanent, which under a different treatment would be heavy and fugitive. This management is repeated for every colour that is employed;—and when any one of these colours is found to be deteriorated by this treatment, it is printed afresh; and so are all the rest, till the workman is satisfied that all the colours are actually permanent.

This tedious process is adopted, however, only

when the manufacturer means to warrant the article; but in all cases, even in those pieces which will not bear washing, the colours are laid on by a brush, as before mentioned.

Whether they are all substantive colours which are thus applied, or whether they use any species of mordant in their fast work, I am unacquainted, as my friend had no information on this subject.

Such are the facts which I have been able to collect respecting the progress of calico-printing from the earliest ages; and also of the present state of the art among the Asiatics. The more difficult part now remains, viz. to give a brief detail of the most important processes of our own artists. This, however, I shall endeavour to do with the utmost plainness, and shall not fail to suggest any improvement that may have occurred to me during my inquiries respecting this very interesting and varied branch of manufacture.

But here it may be necessary to remark, that although I am at full liberty to relate the common outlines of the business, and to suggest such improvements as may have occurred to myself, still there are sundry new ideas and discoveries which have been communicated to me in confidence by some very ingenious men, which I should not be justified in revealing.

I have not yet been able to ascertain when calico-printing was introduced into this country, though

there are various reasons for believing that it is an art, among us at least, but of modern date.

As the whole of this ingenious business, as it is now conducted, depends upon the proper application of a few compounds called mordants, it will be necessary, in the first place, to explain their nature and uses. In doing this, one or two preliminary remarks will assist us.

The colouring substances chiefly employed in this art, are divided into two classes, viz. *substantive* and *adjective*. A SUBSTANTIVE colour is one which is capable of itself of producing a permanent dye; such is the juice of the buccinum [44], used by the ancients for producing the imperial purple; such are also the woad and indigo [45] employed by the moderns for producing a permanent blue; and we may add the metallic solutions, particularly those of iron, cobalt, gold, platinum, and silver, which give various colours, according to the processes by which they are prepared.

By ADJECTIVE colours are meant all those which are incapable of giving permanent dyes without the aid of certain intermedia, which form as it were a bond of union between them and the substances intended to be dyed.

These intermedia are what are known by the term MORDANTS, and they are used for this purpose

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[44] It has been proposed to employ this valuable permanent colour for penciling on fine muslins. I believe it might readily be procured in sufficient quantities, and would prove an important addition to the resources of the British calico-printer.

in very considerable quantities by the calico-printer of the present day.

"The ancient Gauls and Britons were not ignorant of the method of imparting various dyes by means of substantive colours; we have even direct evidence that they excelled in some branches of this art, and possessed valuable secrets in it that were unknown to other nations. Several of the herbs which the Gauls and Britons used in dyeing are occasionally mentioned by Pliny, in different places; but the herb which they chiefly used for this purpose was the *glastum* or *woad*, the isatis of Linnæus; and they seem to have been led to the discovery of its valuable properties in dyeing cloth, from the former use of it in painting and staining their bodies[46]."

Several expedients were also employed by the ancients to produce fast, or, more properly, permanent colours, by means of mordants, as appears from the testimony of Aristotle and Pliny. The chief articles in use at present in Great Britain, are the acetate of iron, the acetate of alumina, and the various solutions of tin, all of which should be very carefully and correctly prepared.

When piece-goods are designed to be dyed of one uniform adjective colour, they are first immersed in

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[45] Dr. Bancroft tells us, that the first mention of indigo, as known in England, is in the Act of the 23d of Queen Elizabeth, chap. 9. where it is called *Ancle*, or *Blue Inde*. Bancroft *On permanent Colours*, page 138.

[46] Henry's *History of Great Britain*, 8vo, vol. ii. page 128.—Pliny's *Natural History*, books 16, 18, 21 and 22.

a solution of one of these mordants, and are then hung up to dry, and to absorb the oxygen of the atmosphere. When sufficiently exposed to the air, they are washed or dunged [47], to remove the superfluous mordant; that is to say, that part of it which is not chemically combined with the cloth; and the pieces are then submitted to a bath of that particular kind of colouring matter which is to be imparted to them.

It may here be remarked, that if a sufficient number of colouring substances should ever be discovered, that have no affinity for any thing but the chemical mordants, the business of calico-printing would be rendered much more easy and simple than it is at present.

Whenever it is meant that a colour should be partially inserted, the mordant is applied to those particular parts only; so that, when the piece is immersed in the colouring bath, no other place will receive the permanent stain. For though the whole surface of the cloth will be coloured, yet having in itself no affinity with the vegetable with which the decoction is impregnated, the whole of the colouring matter will be easily removed by exposure to the air, and the ground of the piece restored to its ori-

[47] The dung of the cow is used in such large quantities by the calico-printer, that it has become an article of great expense. The proportion that is employed is usually about one bushel to one hundred gallons of water, though frequently a larger proportion would be more effectual. The brightness of the colours, and the purity of the whites, are always dependent upon the quantity of the dung employed.

ginal whiteness; while those parts to which the mordant was applied, will retain and fix the colours in a way which will be more fully explained hereafter.

Formerly all calico-printers were bleachers; but in the neighbourhood of London these are separate and distinct trades, and the printer either purchases bleached goods for printing on his own private account, or receives the cloth from his customers in a white state; and, when printed, he returns the identical pieces, and is paid so much per yard, according to the number of colours, for printing them.

Chloride or oxymuriate of lime is the agent generally employed in bleaching; but it appears to me that some other article might be introduced with advantage. For, as the goods are washed in diluted sulphuric acid when they are taken from the oxymuriate of lime, a sulphate of lime is always formed, which becomes fixed in the fabric, and, acting as a mordant when the pieces come into the madder copper, occasions an indelible stain, which in very fine goods often impairs their beauty. If oxymuriate of soda were employed, the sulphuric acid would form a soluble salt with the soda, easily removable by washing. The expense of this article will, however, be always an objection to its use, except for rich and valuable prints.

I am aware that some printers, who are more anxious about the quantity than the quality of the work they perform, would deride this caution, and

say they can obviate the difficulty by washing the goods *before* they are submitted to the sulphuric acid. But I am so confident of the extreme difficulty there is, even in this way, of removing the oxymuriate of lime, that I know the inconveniences above mentioned will very often occur, almost inevitably.

In my opinion every printer should bleach his own goods, for it is impossible always to rely with confidence on the care of those who bleach for hire; and every printer knows that good bleaching is absolutely a necessary preliminary in the production of good printing. Indeed, this is now pretty generally acknowledged in the North of England; for most of the opulent houses in Lancashire and in Scotland, who produce fine work, are bleachers as well as printers.

No people have taken more pains to excel in bleaching than the Irish, and their credit is established accordingly. The German linen is, I believe, generally better than theirs; but the Irish has always the preference in foreign markets, owing to the superiority of the Irish in bleaching and finishing.

By whatever means the bleaching is performed, the printer commences his part of the business in the following manner.

The goods are first DRESSED by singeing off the whole of the nap which is attached to them. This is effected by the following contrivance: Ten pieces

are generally wired together, and wound upon a roller, from whence they are passed over a hot iron, nearly in the form of half a cylinder, and received upon another roller; from thence they are returned to the iron, which is still kept red or nearly at a white heat. The use of repeating this process is to remove the nap more effectually than it would be done by passing it only once over.

The next operation is that of STEEPING, which consists merely in soaking the pieces for 24 hours in a vessel of weak alkaline lye, at a temperature of about 100°. These operations of singeing and steeping are going on at one and the same time, which effectually prevents any accident that might otherwise arise from the effects of the hot iron.

The goods are then boiled or else bowked in a solution of potash; (some workmen prefer to have this alkali in a pure caustic state;) they are then well cleansed, by thorough washing in wash-wheels, or in stocks, to ensure their being entirely divested of the alkali. The intention of thus treating them with potash, is to remove any grease or impurity that may be attached to them, which would otherwise endanger the evenness and uniformity of the colours. This process is called ASHING.

By some observant calico-printers it has been imagined, that the rendering the lye caustic is apt to impair the texture of the cloth; and I doubt not but that this has often been the case. Under the eye of the master, however, I am sure it might be employed with advantage and safety. With advan-

tage, because *mild* alkali has but a slight affinity for the grease; whereas *caustic* alkali forms a real soap with any oleaginous matter, and then the compound is readily soluble in water. And though the alkali be made perfectly caustic, if the solution be sufficiently diluted, it may be used with perfect safety. A convenient mode of mixing the potash and lime, and digesting them with water so as to prepare a caustic lye, will be found described in the Essay on the fixed alkalies.

It may be remarked, that in weaving calicoes the workman generally greases the reeds, in order to make them move easier. Wherever this grease is in the cloth, it becomes fixed by the operation of singeing; and if it be not taken out before bleaching, it will not come out afterwards by the usual process of ashing and souring; for, when the pieces are submitted to a blue vat to be dyed of a uniform self-colour, all those greasy places will be found to have taken the dye in a very imperfect manner. Tallow is also employed for dressing the warp, and this has a baneful effect on all goods which are designed for printing.

If, however, the calico-manufacturers themselves would make a point of preparing the oleaginous matter for the weavers, and would furnish them with nothing but pure VEGETABLE OILS, such as those of rape, linseed, &c., I think it very likely that these inconveniences would not occur; because the stain from *vegetable* is not so indelible as that from *animal* oil.

This defect in the operation of the pale blue dipping is often attended with very serious consequences, so that I know of no subject which better deserves the patient investigation of the calico-printer. I have seen a large number of pieces of printed calicoes which had all taken a solution of iron so as to form an extremely good black; also the acetate of alumina, which had formed with the madder a beautiful red; likewise the citric acid, which produced a perfect resist—and yet, when these goods came into the blue vat, certain parts of the pattern intended for blue, still remained quite white, the indigo having had no action whatever on those parts; a circumstance which is sufficient of itself to spoil the goods, and render the whole expense of printing the other colours totally lost.

To cleanse such goods previously to their being printed, various expedients have been adopted, but I apprehend nothing but a solution of caustic alkali can be depended upon. To prove the effect of any method which may be tried, it is a good way to run the pieces through water, and then to pass them from the water so gradually over a roller, as to give the superintendant an opportunity of examining every inch of the surface; and if any part remains greasy, it will be seen at once, for that part will continue dry, while all the rest of the cloth is wet.

There is another way in which the goodness of bleaching might be proved. Let a few of the suspected pieces be run once or twice through a madder-copper, at the temperature of about 180°. This

will inevitably mark any part that may be imperfectly bleached; whereas, if the operation has been properly performed, they will come out so little stained, that an intelligent workman, who has been used to a madder copper, will at once be satisfied that they contain no impurity that can form a permanent mordant.

The next process in calico-printing is one with diluted sulphuric acid. A quantity of soft water having been poured into a leaden vessel, oil of vitriol is gradually added to it, in the proportion of about twenty pounds of oil of vitriol to every hundred gallons of water, which by weight is in the proportion of about one to forty.

When this mixture has been well stirred, it is ready for use. Sometimes it is employed in this state, at others it is heated to 90° or upwards of Fahrenheit, according to the nature of the work to be done, and the goods are immersed in it. They are not suffered to lie in this acidulous liquor, but are wound by means of a winch over a wooden cylinder, that every part of the cloth may be successively immersed in the fluid, and every part exposed alternately to the action of the atmosphere.

This operation is generally continued for about twenty minutes, and is designed to remove any iron-moulds or other stains which the cloth may have acquired. It has also the effect of neutralizing any portion of potash that may have been left in contact with the cloth. The process is called SOURING.

After this operation it is necessary to wash the

goods thoroughly, that no part of the acid may be left in them, to injure their texture; and this is best effected by means of the wash-wheel. The calicoes are then to be regularly and thoroughly dried, which finishes these preliminary operations, known in the trade by the term PREPARATION; so that those cloths which have passed through these manipulations are said to have undergone a preparation.

Besides the uses already mentioned, there is another advantage attending these processes, viz. that the cloth which has undergone this preparation will bleach sooner, the colours will be brighter, and the whites more delicate, than they would have been had they not gone through these previous operations.

The next process is that of CALENDERING. Here the goods are passed through a set of rollers, which gives them a gloss, and the appearance of their having been ironed. They are now fit for printing. But for copper-plate printing, or cylinder work, the process of calendering is omitted.

In printing fast colours, the artist usually proceeds in this way: He lays the piece of calico, which has been already smoothed by calendering, upon a strong thick table, which is previously covered with a woollen cloth. He then proceeds to apply one or more mordants, as the case may require, for fixing the intended colours. These mordants are applied by means of wooden blocks, with the patterns formed upon them. These blocks were formerly chosen

fo holly, or other hard wood, and the cutting them was a separate branch of the business. Of late years, however, a considerable improvement has been made in this department, by the introduction of brass or copper; that is, the pattern, instead of being actually cut in the wood, is now formed by means of slender pieces of one of those metals being firmly fixed to the block, so as to produce the pattern intended. This alteration was occasioned by the perishable nature of wood, on account of which every printer has incurred great and unnecessary expense. The pattern when thus formed with copper, is not only more lasting, but it has also the advantage of giving greater sharpness and beauty to the impression.

When it was customary to use wooden blocks, the patterns were not enchased in the wood, but the wood was cut away in such a manner as to leave the pattern in relief. It will be obvious that this must always be the case in *block*-printing.

When the mordant is ready, it is mixed up either with flour-paste, or with a thick aqueous solution of gum arabic, gum senegal, or gum tragacanth.

Flour is an article of considerable consumption with the printers for making paste. Some houses buy twenty barrels of American flour at once. Should it be musty or sour from keeping, it is of little consequence for their use; but they are careful to buy none but such as has been made with sound wheat, for if unsound it will be of no value for their purposes. Gum tragacanth is much dearer

than the other gums; but notwithstanding this, it must be had for some styles of work, as no other will answer for any of those colours or mordants which are prepared with nitrous acid. A solution of gum senegal would be coagulated in an instant by any of those preparations. Of late years an article called British gum has also been much in use for the same purpose; so much so that the making of it has become a distinct and considerable trade. It is merely common STARCH calcined till it assumes a cinnamon brown colour, and then pulverized and passed through sieves of various degrees of fineness.

When the colour has been properly mixed with flour paste, or with a solution of either of the gums above mentioned, it is then spread upon a piece of superfine woollen cloth, strained tight upon a hoop. This is placed within another hoop, covered either with sheep-skin or oil-cloth. These hoops are both so broad as to give to each of them the appearance of a tambarine. That which is covered with the woollen cloth is called a *sieve*, the other a *case*. The sieve within its case is now placed in a small tub of gum-water, and is ready for use.

When the apparatus is thus prepared, the mordant is applied by a brush to the surface of the sieve. This is called TEERING.

It should have been remarked, that when a colourless mordant, like the acetate of alumina, is employed, the workman generally mixes a little of the decoction of Brazil wood, or of any other fugitive

dye, with it. This is called SIGHTENING; and is for the purpose of making the pattern more obvious to the workman, that he may see its progress, and the efficacy of the materials, as he proceeds in printing. The manipulation may be thus described.

Taking the block containing the pattern in one hand, the workman applies it gently to the surface of the sieve, so that a sufficient quantity of the thickened mordant may adhere to the figures. When the block is thus charged, he applies it to the calico, and gives it a blow with a small mallet, either slightly or otherwise, according to the nature of the pattern.

This alternate application of the block to the sieve and to the calico, is continued until the workman has gone over the whole piece. In this way several different mordants are sometimes applied to the same piece of goods. This is indeed always necessary, when the finished piece is intended to contain a variety of colours, the different colours requiring different mordants to fix them and render them permanent.

The calico is now removed to a room called the stove, where a certain degree of heat is given to it by means of flues, which go round the room on the inside, near the floor. In this room it is generally continued for at least twenty-four hours[48]. The

[48] This is when common red-liquor has alone been printed; but if citric acid or strong muriate of tin has been employed, less time is sufficient, and for the latter seldom more than half an hour is allowed. See page 184 of this volume.

intention of this is to evaporate the acids used in the preparation of the mordants, and which might otherwise injure the texture, and also to fix the base more surely within the fibres of the cloth.

Whenever acetate of alumina is printed as a mordant upon calico, it appears to me that the pieces ought not to go into the stove until the work has been first thoroughly dried in the open air, because it is well known that the earth of alumina is precipitated from a solution of this salt in a high temperature. I suspect this to be the cause of many of those disappointments which are perpetually occurring in the production of the various shades of yellow and madder reds.

In the operation of stoving, an attention to temperature is of the utmost importance. In general the room is kept at about 90°; but an intelligent calico-printer varies this according to the nature of the work under operation.

It was formerly a practice to expose all those calicoes which were printed with the several mordants, to a hot stove for the purpose of evaporating the acids and fixing the base with more certainty in the fibres of the cloth; but of late years a more convenient method has been adopted, which consists in passing the calicoes by means of machinery along a set of apparatus known by the name of *steam chests*. These are large square cast-iron vessels fixed at some little distance from each other, sometimes on an inclined plane, and in other cases perpendicularly one above the other: these are kept constantly full of

steam, and are connected with each other by bent pipes either of iron or lead. It is so contrived that the pieces of calico are made to pass over each of these heated chests in contact with their surfaces; and in consequence of the access of atmospheric air, as they pass from one of these chests to the other, they are generally found to have become thoroughly dried by the time they arrive at the end of the series. A better apparatus has however been lately invented, consisting of an arrangement of cylinders made of tinned iron or copper filled with steam, and round which the calico is made to pass in succession, as shown at figure 10 of the plate on calico-printing. In this apparatus there is a vane fixed underneath every two of these cylinders, which is moved by means of the steam engine, and agitates the air so as very much to facilitate the drying process. This mode of drying printed calicoes is so effectual, that although the cloth be wound from the heap marked C upon the first cylinder quite in a wet state, it becomes thoroughly dry by the time it has passed over the whole apparatus, and falls in a perfect state on the heap marked D; all which will be better understood by a reference to the plate.

If iron-liquor has been employed in printing the goods, it is an excellent practice to keep them for several days exposed to the atmosphere[49] after their removal from the stove, as the blacks, pompa-

[49] The iron in an acetous solution is in the state of the *black* oxide; but by exposure to the air it acquires a further dose of oxygen, and obtains the state of the *red* or peroxide.

dours, olives, and indeed every other colour prepared with that metal, will increase in intensity; the goods will clean better in the dung-vessels, as will be explained hereafter, and the colours will rise higher and brighter when they come into the copper of bark or madder.

It may be worth an experiment to discover whether the colours containing iron would not be better if they were suffered to be only a *very short time* in the stove, but were hung up instead for several days, exposed to a current of air at the temperature of the atmosphere; as the iron would thus acquire the oxygen slower, and consequently would be fixed more firmly in the fibres of the cloth.

When the pieces have been properly stoved, they are passed, by means of a winch, through water at various temperatures, with a little cow-dung mixed in it. The intention of the dung is to absorb and remove that portion of the mordant which is not actually combined with the cloth, and which otherwise might stain the white or unprinted parts.

This part of the business was formerly conducted in a very uncleanly and negligent way; but of late years some printers have incurred a considerable expense in the construction of their dunging machines, with cocks for hot and cold water attached to them, and thermometers to regulate the temperature. Those erected by Messrs. William Grant and Brothers at Ramsbottom, near Bury, in Lancashire, and by Mr. Wright at Strines, near Disley, in Cheshire, are the most complete of any I have

yet seen, and are well worth the notice of every printer to whom expense is not the first object of consideration.

I suspect, however, that the dung of the cow is serviceable in another way besides that of cleansing [50], though few printers may be aware of the nature of its operation.—It is acknowledged that madder, cochineal, and some other dyes, produce much better colours on woollen than on cotton cloths, owing to the former being of animal, and the latter of vegetable origin. I presume, therefore, that the dung imparts an *animal* matter [51] to the fibres of the cotton, and that this animal matter acts as an additional mordant, and thus more powerfully attracts the colouring particles of the dye, than the mordants alone would be capable of doing.

If a piece of calico, prepared with the acetate of alumina, be divided into two parts, and the superfluous mordant removed from the one by cow-dung and water, and from the other by water only, at the same temperature, it will be found, on passing the two portions through a decoction of weld or quercitron bark, that the yellow will be much more intense and bright in that which had been submitted to the action of the cow-dung.

The process of DUNGING calicoes is an operation that varies in time from five to forty minutes, ac-

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[50] To *cleanse* calicoes by immersion in a dung-vessel, may appear to be a strange phrase; but as this is the technical language of the trade, no other term could be employed with propriety.

cording to the style of the work. The pieces are then taken to the river or wheel, to be more effectually washed; and after this they are passed through tepid water, in order that the workman may be assured that every impurity is removed.

His next care is to provide a copper boiler of pure cold water, into which a sufficient quantity of madder is broken, and then a fire is lighted underneath the copper. The calicoes, printed and rinsed as above, are now put into this boiler, and from the time they are immersed, the workman never ceases to turn the winch, so as to pass every part of the goods repeatedly through the liquor, until the whole acquires a boiling heat. Indeed, this operation is sometimes continued for ten or fifteen minutes after the bath of madder actually boils, when the pieces are taken out and washed thoroughly. In most of the large calico-works, a considerable improvement in the method of maddering has been adopted since the publication of the first edition of these Essays. This consists in giving a perpetual motion to the calico by means of the steam engine. The ends of several pieces are fastened together, and then they are put into constant motion through the madder vessel, whereby the colours are rendered more uniform; and one man is enabled to attend to three dyeing-vessels at one time, which is found to be a great economy of labour.

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[51] Berthollet, who analysed the dung of the cow, found in it a substance partaking of the nature of animal *bile*.

Madder is one of the most valuable drugs we have, for a variety of purposes in dyeing and calico-printing: as it is the agent by which the best and most permanent blacks are produced; also the finest purples, and every shade of red from a pale pink to a crimson. But perhaps it may not be generally known that this article improves by age. For instance: If a quantity of madder-roots be ground, and then packed tight in a cask, so as to exclude the air, and kept thus for six months, they will dye a much better colour, and go much further, than they would have done had these roots been used as soon as they were ground.

The process which is called MADDERING, has the effect of imparting all the requisite colours to the goods by means of *one* operation, which may be thus explained:

While one mordant precipitates the colouring matter of the madder to a red, another precipitates a different portion of it of a purple, another precipitates it black, and so of every possible shade, from a lilac to a black, and from a pink to a deep red.

If a portion of weld or bark be added to the madder, every shade from a brown to an orange may be produced; whereas, if weld or bark alone be employed, all colours between a dark olive and a bright lemon can be imparted to the cloth. These changes are all occasioned by the play of chemical affinities, for the knowledge of which we are indebted to the improved state of chemical science.

The only materials which are employed by the

calico-printers for the production of fine yellows are the quercitron bark and the weld plant; the former is the bark of a peculiar kind of oak growing in America, the latter is the produce of our own country. The weld plant (the *reseda luteola* of Linnæus) is for the most part cultivated about Doncaster in Yorkshire. It is found, however, that nothing impoverishes the land so much; otherwise it produces a very heavy and profitable crop.

Here it may be worth remarking, that whenever it is of consequence to produce the finest yellows or more delicate lemon colour, it is necessary to dry the pieces in the open air, as the stove would not fail to injure such colours; for stove-drying has always a tendency to convert a yellow to an orange. It is also necessary to be equally careful in the operation of dunging the mordants for these pale yellows; for, should this be done at a higher temperature than 96° or 100°, their beauty will certainly be impaired. There is another advantage in this, viz. by dunging at this low temperature, the dyeing may be completed even at 110° or thereabouts, which will give a much livelier colour than where a higher temperature has been employed.

The mordants generally used in calico-printing, are acetate of iron for browns, blacks, lilacs, &c.; and acetate of alumina for all the different shades of reds and yellows.

The best method that I am acquainted with of preparing the acetate of iron for making the common black colour for calico-printing is as follows:—

Take the iron liquor of its full strength, or lowered with one or two waters according to the goodness of this mordant in the first instance, and then add about 2½lbs. of flour to every gallon of the fluid, more or less according to the goodness of the flour and the kind of work for which it may be designed. Having well incorporated the flour with the iron liquor, let the whole remain twelve hours or more. After this it is to be boiled for about half an hour, or till the whole be converted into a paste of due consistence, when it will be fit for use. The materials become better incorporated, and the colour is found to work better, by lying thus long before it is finished by boiling.

Formerly the acetate of iron was made by digesting old iron hoops in sour beer, or in very weak vinegar; but of late years it has chiefly been made with the pyroligneous acid [52], the oleaginous impurities of which tend, in some cases, to improve the mordant.

Blacks are also produced by the nitrate of iron and gallic acid; the mixture is called chemical black. The nitrate of iron is made by dissolving metallic iron in a peculiar kind of aqua-fortis. Common aqua-fortis will not answer for this pur-

[52] If wood be submitted to an intense heat, when inclosed in an iron vessel of any kind with a proper aperture to allow the vapour to pass, this vapour on being condensed forms the acid in question, and is now known to be a kind of impure vinegar. The wood in this case is converted into *charcoal*, of which a great deal is prepared by this process, particularly for the formation of gunpowder.

pose; for, though it may dissolve the iron with rapidity, part of the metal is apt very soon to precipitate; which not only weakens the colour, but leaves the remainder so acidulous that there is always a danger of such a preparation injuring the texture of the cloth.

Chemical black is made by mixing a decoction of galls with the nitrate of iron just described; this produces gallate of iron, and probably some tannate of that metal: the disengaged nitrous acid then dissolves the two newly formed salts. The colour called chemical black may therefore more properly be said to be an union of the colouring matter of galls with the per-oxide of iron, than a mixture of gallic acid with nitrate of iron. The gallic acid is probably like the pyroligneous, or nothing but the acetous acid holding a peculiar vegetable substance in solution; and either the muriate or the sulphate of iron, if applied to cloth in conjunction with the colouring matter of galls, will in time produce as intense and durable a black as the nitrate; but the difficulty of thickening the solutions of these salts, and the time which is required to convert their base into a per-oxide, render them less fit for the calico-printer's purpose.

It is, however, necessary to remark that the black

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[53] Nitrate of iron was not applied to calico-printing till within the last fifty years. This discovery formed an important æra in the trade, as it afforded the manufacturer the means of varying his styles of work in a multiplicity of ways and forms, which till then were entirely unknown.

which is formed by this solution of iron, is produced in a different way from blacks in general; for, when common iron liquor is used for this purpose, it is first printed on the calico; and when it has been sufficiently oxidized by exposure to the air, the goods are boiled in a decoction of madder, which renders such parts as had been printed with the acetate of iron an intense black. But the black from nitrate of iron and galls is applied at once to the cloth, and is not afterwards increased in intensity, or raised, as it is termed, by dyeing.

The calico-printer by using a black ready formed is thus enabled to mix it with other colours, in cases where by dyeing alone it could not be produced, as in conjunction with yellows and olives, raised by weld or quercitron bark.

The acetate of alumina is prepared by a mixture of the sulphate of alumina and potash with acetate of lead, both in a state of solution; so that, on the theory of double decomposition, sulphate of lead is formed, which precipitates, while the acetate of alumina remains in solution.

Since the demand for this article has been increased on account of the extension of the printing-trade, it has been prepared from the pyroligneous acid, by means of lime and alum. The following is the method:

The pyroligneous acid is first passed through a still, to divest it of a portion of the oil or tar which is always dissolved in it; it is then saturated with lime or whiting; and lastly, the acetate of lime

thus formed, is decomposed by a heated solution of sulphate of alumina and potash. The result of this double decomposition is sulphate of lime, which precipitates, and acetate of alumina, which is drawn from the sediment of the calcareous sulphate, and preserved for use.

And here it may be necessary to caution the manufacturer against a misfortune that may befall him if he be not conversant with the chemical nature of the substances he employs.

Magnesian limestone abounds in Derbyshire and in some of the adjacent counties; and should a maker of acetate of alumina employ such lime in his process, the article which it would produce would in all probability be entirely unfit for the use of the calico-printer. But I must be more explicit.

In employing the common lime in conjunction with alum, a sulphate of lime will be formed, as mentioned above, and this being nearly an *insoluble* salt, will precipitate. But here, sulphate of magnesia would also be formed, which being a *soluble* salt, would remain in solution, and increase the specific gravity of the liquor, a circumstance which would be very apt to occasion the deception which I am anxious should be avoided. If magnesian limestone be employed, the liquor will appear good by the hydrometer; but, as it will contain more Epsom salt thanacetate of alumina, it will be unfit for every purpose for which it was intended.

While speaking of acetate of alumina, I cannot

avoid remarking, that the process which has just been described for making this mordant, and which is followed invariably by many of the manufacturers in the North, is extremely improper, on account of the lime which is employed in it, be the lime ever so good, as that earth is very prejudicial to every species of red dye. The proper way of making it, though more expensive, is that which was originally pointed out by Berthollet, and which consists in decomposing sulphate of alumina and potash (common alum) by means of saccharum saturni, or acetate of lead.

In reverting to the remaining processes of the print-work, it must be noticed, that when the goods have passed through the weld or madder copper, they are usually carried to a boiler containing wheat-bran and water, in which they are winched for a considerable time, for the purpose of freeing the white grounds from the stain which they had acquired from the madder or the weld. This process always impairs, in some measure, the intensity of the colours; but it is a necessary operation, as there is no other mode so convenient for removing the stain which is always given to the white part of the print by the madder, the bark, or the weld, which has been used in dyeing it.

Branning has also the effect of giving a pink hue to all madder reds. But it is not generally known what a peculiar richness may be imparted to madder colours, by raising them with a mixture of bran and madder; that is, by mixing a portion of bran

with the madder in the first instance. I have myself sometimes produced colours in this way whose brilliancy has astonished me.

This mode of dyeing red with a mixture of bran and madder is called in the trade *Growse's* or London pink, and was invented by a journeyman calico-printer near London, of the name of Growse, who sold the recipe for 100 guineas. In this process the acid of the bran prevents the precipitation of the *fawn-coloured* particles of the madder, and the red produced is consequently more rosy and pure.

Madder contains two distinct species of colouring particles, a beautiful red or rose colour and a degraded yellow or fawn colour—both are precipitated on the cloth, in the usual dyeing process, to the great injury of the *tint* obtained. The object of the tedious Turkey-red process is to fix the red colouring particles so firmly as to allow the fawn-coloured ones to be dissolved and discharged by long boiling in solution of soap or soda, by oxymuriate of soda or by acid solutions of tin. A dilute supersulphate of potash has lately been used with success for this purpose in France[54].

It frequently is the case, however, that goods will not bear to be sufficiently branned to clear the whites entirely by that one operation[55]; such goods,

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[54] See "A Collection of Observations on Madder," by Berthollet, *Annales de Chimie*, tom. iv. page 102. M. Watt "On the Properties of Zealand Madder." *Ibid.* page 104. Vogler "On dyeing Cotton with Madder." *Ibid.* page 109.

[55] The temperature at which the operation of branning is per-

therefore, are partially cleansed in the branning-copper, and are then laid on the grass for some days, until they become perfectly clean and white.

But, within the last few years a new method has been introduced, which consists in immersing the pieces for a certain time in a very weak solution of one of the bleaching salts, such as oxy-muriate of potash, soda, or magnesia. This simple process, which effects in a few minutes what would require more than as many days in grass-bleaching, is now much practised, and promises very soon to supersede crofting entirely. This is a most important improvement, as some of the large printers formerly required as much land to spread out their goods upon, as would make a farm of a very considerable size.

Besides the kinds of calico-printing already mentioned, there are others which it will be proper to notice in this place. Of these, what is called resist-work, is now done in considerable quantities. It is conducted in the following manner:

A certain preparation of copper, mixed either with flour paste, with gum, or with pipe-clay and gum, is printed on the calico, in any shape or of any pattern that may be desired[56]. When this is sufficiently dry, the goods are repeatedly dipped in

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formed, is very important. If bark yellows are dyed at 100°, it is customary to bran such goods at 115° or 120°, as it is a principle always to bran at a higher temperature than the goods are dyed at. Madder-work must be branned at a boiling heat.

[56] The sulphate, the nitrate, the muriate, and the acetate of

the blue vat till they have acquired that depth of tint which may be required. The art of making an indigo-vat, or blue-vat as it is sometimes called, consists in forming such a mixture of lime and sulphate of iron as shall most effectually deoxidize the indigo; as indigo has no affinity for cloth in its natural or oxygenized state. Hence, those parts of a piece which are printed with a solution of copper will never be dyed blue in one of these vats; because the deoxidized indigo becomes oxygenated the moment it touches the copper, which parts with its oxygen to the indigo, and occasions it to become insoluble, and consequently incapable of forming a dye.

Thus, while sulphate of iron has the power of deoxidizing indigo, sulphate of copper, or any other salt of that metal, is incapable of retaining its oxygen, whenever it comes in contact with that singular substance in a state of deoxidizement; and it is a curious instance of the different degree of intensity by which oxygen is held by the different metals.

I suspect, however, there is often great waste in the management of these vats, and that the contents are often thrown away long before the indigo is spent, in consequence of the want of a due admixture of the lime and the sulphate of iron with the

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copper have all been employed for preparing the resist-paste; but I believe the sulphate is the best for the purpose, unless a very concentrated solution of the four salts were prepared by successively dissolving each of them in pure water.

colouring matter; whereas, if a dyer or calico-printer be acquainted with chemical science, he will understand the nature of the operation of these substances upon each other, and hence can be at no loss how to keep up the vat to its original strength, by replenishing it occasionally with one or other of the ingredients as may be required.

The fact is, that indigo, unless it be de-oxidized, is insoluble either in the alkalies or the alkaline earths; but when this is effected by the iron of the copperas, the lime dissolves it, and forms it into a perfect solution of indigo. At first a portion of the lime abstracts the sulphuric acid from the copperas, and precipitates with it in the state of sulphate of lime. The detached metal being now in the state of the protoxide of iron, and having in that stage of its oxidizement a great affinity for oxygen, it takes it from the indigo, and thus becomes changed to the per-oxide of iron, which being insoluble precipitates likewise. Thus the acid and the base of the sulphate of iron are at length both precipitated, when the remaining portion of lime seizes the deoxidized indigo and forms with it the solution desired. When the principle of the blue-vat is thus properly understood, it is an easy thing for the manager at any time to discover which of the three materials is deficient, and to add it accordingly. I am the more desirous of offering these remarks, because I have many times heard the proprietors of a manufactory declare that they have occasionally thrown away the whole contents of a new vat, con-

taining many pounds worth of indigo, because the foreman or manager of the works had not observed the due proportions of the lime and the copperas to put the indigo into a proper state for working; and they have an idea, that if it is once wrong it must be always so, and therefore they throw it away without attempting to correct the error.

To revert to the process of resist-work, it is necessary to say, that when the pieces have been sufficiently immersed in the blue-vat and have been washed and passed through diluted sulphuric acid, those parts which had been printed with the preparation of copper, are found to be preserved a good white; the preparation having effectually resisted the operation of the indigo, though all the other parts of the cloth have received a permanent dye. The various deep blue calicoes with white spots or white figures, which are now so common, are generally done in this way; and by a similar management with subsequent dyeing in madder, in weld or quercitron bark, figures in red or yellow (as the case may be) are exhibited upon a blue ground.

In some particular styles of work the operation of certain colours is resisted by means of stopping out with wax; but this is too expensive a method to be adopted often, in these times, when it is the object of every manufacturer to finish his prints at the least possible expense. Formerly this mode was very generally practised, and wax was consumed in very large quantities by this process [57].

[57] In the East Indies wax is still used for preserving the whites in calico-printing.

In printing those silk handkerchiefs called Bandanas, a process called waxing is still followed. It consists in making a preparation of tallow and rosin very liquid hy heat, and in printing it in that state with a block upon the silk. When such goods are passed through the blue-vat, those parts which are covered with the tallow and rosin are preserved from the action of the indigo, and remain white, while all the rest is dyed a fast blue. The method afterwards taken to discharge a part of this blue, and produce yellow, orange, &c. will be mentioned hereafter.

A very singular-looking substance was discovered a few years ago near Stockport, which being handed about from one to another, created considerable interest in that neighbourhood. Every body supposing it to be a natural production, specimens of it were sent to a variety of persons into various parts of the kingdom, for their opinion and analysis, and among others a portion was sent to myself. However, after every one had been busily engaged in examination and conjecture, respecting this unknown substance, it was announced, that some seventy or eighty years before, a calico-work had stood on the spot where the article was found, and that this was nothing more than a large heap of the refuse compound of flour, wax, and gum, above mentioned.

The reader will perceive that these *resists* are employed for the purpose of preserving certain parts of a piece white, and of giving other varieties to those goods in which blue is the predominant colour: but if the ground is to be white, and the piece is

only to have one small object[58] in indigo blue, such as a single sprig, then a different management is necessary, and the colour is imparted by a process which is called *pencil-blue*.

Here the indigo is deoxidized by means of orpiment, which is a sulphuret of arsenic; and formerly, whatever objects were done with it were put in by means of a pencil: hence its name, PENCIL-BLUE.

Pencil-blue is composed of the following ingredients, viz. Ten ounces of indigo finely ground in water; twenty ounces of quicklime in lumps; the same quantity of potash of commerce, or the impure sub-carbonate of this alkali; and ten ounces of orpiment. These proportions require one gallon of water, and when the whole has been properly mixed, and time has been allowed for the sediment to subside, the clear colour is to be carefully poured off and thickened with gum senegal.

The intention in using this preparation had always been to impart it to the calico, before the indigo had time to recover its oxygen: hence a small quantity only was mixed at once, or no more than could be penciled on in a very short time; but the inconvenience which attended this plan, gave rise at length to an invention which has nearly superseded the use of the pencil.

The invention to which I refer is the spring-sieve, which may be thus described:—A fine canvass

[58] *Object* is a technical term, belonging to this branch of manufacture.

sieve is suspended within a tub of pencil-blue colour, so contrived that the canvass should be in contact with the colour, and follow it as it wasted. But as the colour was consumed the sieve did not always exactly sink with it, which occasioned great uncertainty, and sometimes considerable disappointment from the admission of too much atmospheric air:—to obviate these inconveniences many schemes were resorted to, but none of them completely answered the purpose.

This utensil has, however, now been much improved by a particular friend of mine, who has kindly allowed me to give a plate [59] and description of it; and I doubt not but I shall have the thanks of some of the manufacturers of printed cottons for having made public an invention of so much utility and ingenuity. It may be thus described:

A is the box which contains the colour; B is the sieve which floats within the colour; C. C. C. C. are the four springs which keep the canvass of the sieve close down upon the dissolved indigo; and D is a vessel from which the blue-tub is constantly supplied with colour, as the same is exhausted by the printer, and is upon the principle of a common bird-fountain [60]. The improvement chiefly consists in the addition of this vessel, which in the beginning is completely filled with the prepared indigo,

[59] See the plate on calico-printing, fig. 11.

[60] The stop-cock, which is placed in the tube, is to prevent any loss of colour, in case the barrel should by any accident admit atmospheric air, and cause the box to overflow.

and closely corked and sealed, to prevent the possibility of the access of any atmospheric air.

Another kind of process remains to be noticed, called CHEMICAL-DISCHARGE work. Here the cloth is first dyed of some uniform colour, by means of a mixture of iron-liquor, and some one or more of the common vegetable dyeing substances; and calicoes thus prepared are said to be dyed of self-colours. They are then washed and dried; and when properly pressed or calendered, they are fit for receiving any pattern whatever, according to the taste or design of the artist.

This is generally effected by means of the mineral acids, which are previously prepared for the purpose, by dissolving in them a portion of one or more of the metals, according to the nature of the dye which is intended to be discharged, or of the colour to be produced. In doing this, care is taken that the discharging liquor be made so as to be capable of dissolving the iron which is contained in the dye, and which is always used in such quantity as to cover, or at least to disguise in a great measure, the other colour or colours which had been employed with it, and at the same time to act as a mordant in beautifying and fixing those colours.

Thus a piece treated with a decoction of Brazil-wood, and dyed black by being padded[61] with iron-

[61] By the term *padding* is understood the operation of passing the pieces from a roller through a trough containing a solution of iron, or any other mordant. *Blotching* is another term used in calico-printing, and is synonymous with padding.

therefore, are partially cleansed in the branning-copper, and are then laid on the grass for some days, until they become perfectly clean and white.

But, within the last few years a new method has been introduced, which consists in immersing the pieces for a certain time in a very weak solution of one of the bleaching salts, such as oxy-muriate of potash, soda, or magnesia. This simple process, which effects in a few minutes what would require more than as many days in grass-bleaching, is now much practised, and promises very soon to supersede crofting entirely. This is a most important improvement, as some of the large printers formerly required as much land to spread out their goods upon, as would make a farm of a very considerable size.

Besides the kinds of calico-printing already mentioned, there are others which it will be proper to notice in this place. Of these, what is called resist-work, is now done in considerable quantities. It is conducted in the following manner:

A certain preparation of copper, mixed either with flour paste, with gum, or with pipe-clay and gum, is printed on the calico, in any shape or of any pattern that may be desired[56]. When this is sufficiently dry, the goods are repeatedly dipped in

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formed, is very important. If bark yellows are dyed at 100°, it is customary to bran such goods at 115° or 120°, as it is a principle always to bran at a higher temperature than the goods are dyed at. Madder-work must be branned at a boiling heat.

[56] The sulphate, the nitrate, the muriate, and the acetate of

the blue vat till they have acquired that depth of tint which may be required. The art of making an indigo-vat, or blue-vat as it is sometimes called, consists in forming such a mixture of lime and sulphate of iron as shall most effectually deoxidize the indigo; as indigo has no affinity for cloth in its natural or oxygenized state. Hence, those parts of a piece which are printed with a solution of copper will never be dyed blue in one of these vats; because the deoxidized indigo becomes oxygenated the moment it touches the copper, which parts with its oxygen to the indigo, and occasions it to become insoluble, and consequently incapable of forming a dye.

Thus, while sulphate of iron has the power of deoxidizing indigo, sulphate of copper, or any other salt of that metal, is incapable of retaining its oxygen, whenever it comes in contact with that singular substance in a state of deoxidizement; and it is a curious instance of the different degree of intensity by which oxygen is held by the different metals.

I suspect, however, there is often great waste in the management of these vats, and that the contents are often thrown away long before the indigo is spent, in consequence of the want of a due admixture of the lime and the sulphate of iron with the

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copper have all been employed for preparing the resist-paste; but I believe the sulphate is the best for the purpose, unless a very concentrated solution of the four salts were prepared by successively dissolving each of them in pure water.

calico-printing of the country[62]; and a great deal of very excellent printing is now done in various parts of the kingdom, especially for the best chintz-work and other furniture patterns. But, in what is called fast-work, there is a great variety of qualities, and some of it little deserves the name of permanent.

The mention of permanent colours reminds me of a very valuable GREEN which was invented some years ago by a Mr. Islet of London, and which deserves to be noticed in this Essay. This colour, which was secured to him by His Majesty's Letters patent, is produced by printing ground indigo mixed with a peculiar kind of solution of tin, and in then fastening the indigo within the fibres of the calico by means of that process, which is well known to printers by the technical designation of *china-blue dipping*[63]. After this the goods are dyed in a copper of bark or weld, which converts the blue to a green, and the whites are afterwards cleansed by croft-bleaching, &c.

Having myself formed a very high opinion of this invention, I had several interviews with Mr. Islet, soon after he obtained the patent, and from him was fully informed of the whole process.—This I have since repeated for the purpose of ve-

[62] To this end great improvements have of late years been made in the method of grinding madder-roots, by separating the inferior parts and dividing the whole into two or three different qualities. Thus the printer is enabled to apply the finest, which in this way is made equal to Dutch-crop-madder, to his best work, and the other can be laid by for inferior purposes.

rifying the detail in all its branches; and I am satisfied that it is one of the most beautiful and PERMANENT colours that has ever been fixed upon cotton.

There is another mode of producing very beautiful blues which has been much practised lately, and therefore deserves notice. This consists in printing some solution of iron, and then passing the goods through a very dilute and neutral solution of prussiate of potash. The prussian blue which is thus formed upon the cloth may be rendered tolerably permanent by a variety of expedients, and this by means of any of the yellow dyes may afterwards be formed to any shade of green or of olive.

Begging to be excused for the irregularity of these digressions, I must not forget to revert to that other kind of discharge-work which I have engaged to describe, and which I will now attempt as concisely as is consistent with perspicuity and correctness.

Here, the agent which is employed is the citric acid, and this is used in various states of concentration according to the purpose to which it is to be applied, and the strength of the ground intended to be discharged. It is chiefly employed for the production of white figures upon self-coloured grounds produced by madder and sundry other dyes. For

[63] China-blue is produced thus:—Indigo ground fine, and then thickened, is printed upon the cloth, and afterwards it is dissolved, and chemically united to the fabric, by alternate immersion in a solution of sulphate of iron and in lime water.

this intention the acid, in whatever state of concentration it may be, is mixed with either gum or with flour-paste [64] to a proper consistency for the block, the plate, or the cylinder, and from thence it is transferred to the piece; and wherever it attaches, the mordant, whether iron or alumine, is discharged, and a delicate white arises in its stead [65].

The acid here referred to is produced from the juice of limes or lemons, and formerly it was not employed by the calico-printer until it had been reduced to the utmost point of concentration, and appeared in a crystalline form. Even then, it was not thought sufficiently pure, but was dissolved again, and redissolved and recrystallized, until it became as white and pellucid as any other pure salt in a crystallized state, and was then generally sold for 36*s*. the pound, at which high price it could only be employed on the best styles of work. Now, however, it is oftener used in the brown, or first state of crystallization; and some of the larger printers purchase lime juice, and concentrate it themselves; and in many cases they use it largely both for discharge- and resist-work, without crystallizing it. More on this subject may be seen in the Essay on Citric Acid, which was written with the hope of rendering an essential service to a large body of manufacturers in various parts of these kingdoms.

This mention of discharge-work by citric acid [66],

[64] When citric acid is used for resist-work, it is always mixed with gum senegal and pipe-clay. The clay gives it a greater body, and likewise acts mechanically as a resister.

[65] It should be understood, that the discharge is printed upon

reminds me of another species of discharge, which is employed by the printers of Bandana handkerchiefs, and which I am under the promise of noticing before I conclude this Essay.

The agent which these printers employ is the nitrous, and sometimes the nitro-muriatic acid. It is used for the purpose of putting yellow figures upon blue silk handkerchiefs. The following is the process which is principally adopted.

Aqua-fortis, or nitro-muriatic acid, of such a strength as is suitable for the kind of blue which is intended to be discharged, is mixed either with gum tragacanth, or with flour-paste, to a proper consistence, and in this form it is printed on the silk, by means of a common block, on which the intended pattern is cut. The consequence of this is, that wherever the acid attaches, there the original colour is discharged, and a yellow dye is produced in its place. The pieces are then steamed, by passing them over a vessel containing boiling water, which gives brilliancy to the colour and finishes the operation.

If a stronger dye than the usual yellow, or even a deep orange be desired, all that is necessary is to

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the mordants before the goods are dyed. In using citric acid for this purpose, a portion of one of the mineral acids is sometimes mixed with it.

[66] Mr. Thomson, a scientific printer, who has an establishment near Clithero, which is carried on under the firm of Thomson and Chippendale, has taken out a patent for discharging the Turkey-red dye by means of the citric and oxy-muriatic acids; and the work executed in this way has a very pleasing effect.

immerse the goods, for a moment, in lime water, or in a solution of lime and potash; and by varying the proportions of these ingredients a great variety of shades may be produced.

It must be noticed that this method is applicable only to the discharge of the colour from *silk* handkerchiefs; the process for producing the spots on *cotton* Bandanas being entirely different. This manufacture, which is of considerably more importance than the former, was established some years ago in Scotland, for the purpose of producing imitations of the Bandana handkerchiefs which are imported from India. It is conducted in the following manner.

Pieces of fine calico are dyed by the Turkey-red process, of a colour as nearly approaching to scarlet as can be produced on cotton by that means; and, upon this plain dyed calico, white spots are produced by a method to be described hereafter. The pieces of calico having been bleached to a perfect white before they are dyed Turkey-red, the present object is, not only to discharge the dye on certain parts of the cloth, but by the same agent to restore those parts to their original whiteness.

These discharged parts are usually in the form of spots, sometimes round and sometimes square or triangular, and these marks or spots are produced by the action of a chemical liquid, while the pieces of calico are under the action of a powerful press. The machinery for this purpose is made in an expensive manner, as it is required to be of very great

strength, and it is put together with the utmost exactness.

To this press two horizontal plates are adapted, for the purpose of receiving the calico which is to be placed between them. The pattern intended to be given to the handkerchiefs is first marked upon these plates; and in the bottom plate holes are cut of the exact form and size of the intended spots; whereas, in the upper plate every spot is marked out by a small copper tube which goes through the plate and is firmly cemented within it.

When the plates are about to be fixed, there is a contrivance for ascertaining that the orifices of the tubes in the upper plate are exactly perpendicular to the respective holes in the under plate; which is a circumstance of the utmost importance, as the discharging liquor which is poured into the tubes is designed to pass through the folds of calico into the corresponding holes in the lower plate.

The apparatus being thus prepared, the handkerchief pieces are neatly folded into squares of the size of a single handkerchief and of the thickness of about ten or a dozen folds. One of these pieces, consisting of ten or twelve handkerchiefs, is then laid smoothly upon the lower plate, and is so disposed as to lie square with the plate. By means of a lever, the cover of the press, to which the upper plate is attached, is then lowered, and by continuing the action of the lever, these plates, with the folds of calico between them, are screwed firmly together.

The consequence of this is, that the ends of the

tubes fixed in the upper plate, are brought to press upon the surface of the cloth; and as these are made to press upon it with great force, and as each tube has a corresponding hole immediately beneath it in the under plate, it is evident that the fluid which is poured into these tubes will be directed into the holes below, and cannot pass in any other direction.

When things are thus arranged, and the press is firmly screwed down, a very dilute solution of chloride of lime, containing a small portion of sulphuric acid, is poured upon the upper plate of the press; and as this plate has an iron rim round its upper surface, the fluid which is poured upon it is determined into the tubes, and as it percolates through the cloth it discharges the colour on those particular parts, and passes off through the holes of the lower plate into a trough placed underneath to receive it.

It is observable that the chemical liquid is prepared sufficiently strong to discharge the colour in the course of about ten or twelve minutes, and yet not so powerful as to endanger the fabric of the cloth; and that the great pressure of the screw prevents the fluid from spreading beyond the precise limits marked out by the tubes and the corresponding holes underneath.

As soon as the discharging liquor is found to have entirely passed through, the press is slackened, and the cloth is removed to make room for another piece, which is immediately substituted; and in this

way the process is continued throughout the day without interruption. One press, requiring the attention of two men only, will print fifty pieces, containing one dozen handkerchiefs each, in the course of the day.

When the pieces are first taken from the press, the spots which have been produced by the discharging liquid are not perfectly white; it is therefore necessary to have recourse to a subsequent process similar to the one usually employed for clearing the whites on common printed calicoes; and this not only removes every stain, but also heightens the brightness of the Turkey-red dye. I am aware that at one time there was a general complaint of such handkerchiefs, after frequent washings, becoming tender in those parts which had been acted upon by the chemical liquor: this I think must be owing either to the employment of a liquor too much concentrated, or to the remains of the acid not having been perfectly removed before the goods were dried and pressed for sale; as I am persuaded that with due caution the process may be safely conducted.

When speaking of yellows, it was my intention to have mentioned, that there is a mode of producing yellows on calico which is not very frequently practised, and yet has a very good effect. The process is as follows:

A strong decoction of quercitron bark, thickened with gum tragacanth, is to be mixed with a portion of very pure muriate of tin, and this, when printed

with the usual management, will produce a colour of great brightness and durability. I mention this the rather, because very many pleasing effects may be obtained by this method which cannot be produced in the usual way, by means of the acetate of alumina, and any of the yellow dyes that may be employed with it.

There is one very important advantage which this mode possesses, viz. that should it be necessary to pad a piece in diluted acetate of alumina to obtain a pale lemon ground, the yellow figures, previously imparted by the above process, will not give out any part of their colour to the second mordant; whereas, whenever a strong yellow has been produced in the common way, the pattern is very apt to spread and become irregular, and oftentimes to stain the white ground, when the piece comes a second time into the acetate of alumina.

The most expensive kind of calico-printing called CHINTZ-WORK still remains to be described. The term chintz-work is descriptive of that kind of calico-printing which is employed for window-curtains and other furniture, and it differs more in the richness and variety of the colours, than in any other circumstance.

In relating the processes by which these beautiful prints are produced, I shall suppose the calico to be already properly bleached and smoothed ready to receive the impressions of the block. The first thing then to attend to, is to apply the mordant

for the colour which is intended to be imparted in the first instance. Thus, if a black be designed, a mordant of acetate of iron, commonly called iron-liquor, is thickened with gum, and printed upon the cloth in any pattern that may have been selected for the purpose. If this same mordant be diluted with water, it will form a proper mordant for a purple; and the same, still further diluted, will, when it comes into the dyeing-copper, form a lilac. In this way, all the varieties of shades from a pale lilac to a strong purple, and from a purple to a black, may be produced by acetate of iron diluted with various portions of water, and then dyed with madder.

In like manner, a colourless solution of acetate of alumina thickened with gum or flour-paste, forms a mordant for dark red; if diluted with water, it makes a common red; and by diluting it further and further, every shade of pink may be produced. Again, by the admixture of acetate of iron and acetate of alumina, a mordant for chocolate colours, maroons, &c., is formed, either approaching to the purple or the red, according to the admixture; that is, according to the proportion of either of these original mordants which may predominate in the mixture.

When these several mordants have been printed upon the calico, they are allowed to dry for two days or more in a stove, or drying-house; they then go through the operation of dunging, which consists in rinsing them in warm water in which a little

cow-dung is diffused, as has been already described. When the pieces are sufficiently dunged, which is not the case till all the superabundant mordants are removed, they are well washed in clean water, and then boiled in a decoction of madder, until the madder-bath is exhausted. In consequence of different mordants having been applied to the cloth, this one boiling in the madder-liquor will at once produce all the colours above mentioned. When the pieces are thus dyed, they are to be rinsed in cold water, and laid upon the grass to bleach. By this exposure to the air for a few days, the whole of the ground to which none of the mordants had been applied, will become perfectly white.

The processes which have now been detailed, will produce what is called *common* chintz-work; but if it be desired to make the goods still richer, by the addition of yellows, bright olives, drabs, &c., the cloth must undergo another series of operations, which may be thus described:

Upon those parts of the calico which still remain white, any of the above mordants may be printed, according to the effect designed to be produced; after which, all the preceding managements are to be repeated, except that instead of boiling in a decoction of madder, they are to be immersed for about half an hour, more or less, in a warm decoction of quercitron bark, (the *Quercus nigra* of Linnæus,) a most important dye-wood, introduced by Dr. Bancroft, and which is found to give out a

much brighter colour to *tepid* water than it does when treated with *boiling* water, or with water nearly approaching to that temperature.

The effect produced upon these prints by an immersion in a lukewarm decoction of this American bark, will be quite different from that produced by the madder; upon those parts of the cloth where the mordants have been printed which before produced a black, a dark olive only will be apparent; and instead of pompadours will be drabs, and instead of reds we shall have yellows, which will vary in intensity according to the strength of the aluminous mordant.

Again: a further variety may be given to these prints, if the yellow mordant, or acetate of alumina, be applied to any of the colours which have already been dyed with madder; but this must be done before the pieces are immersed in the decoction of bark. This application will convert the reds and pinks into different shades of oranges, and the lilacs into cinnamon colours. By means of these different processes, an endless variety may be given to the goods, and a calico-printer of taste will never be at a loss how to produce a pleasing effect, whatever may be the patterns which he has to imprint upon the cloth. This second immersion in the dyeing vessel will, however, give a yellow tinge to the remainder of the whites, but a short exposure on the grass will obliterate it.

When chintz-furniture-prints are designed to have as much variety of colouring as possible, a part

of the remaining white is often coloured blue or green, or of any shade between those colours, by a still different process. This is done with what is called pencil-blue, which is a preparation that has already been described. The blue is given by putting in the prepared indigo with a pencil; and the green is produced by pencilling some of the same colour over certain parts of the pattern which has already been dyed yellow.

When these colours have been imparted, the printing is said to be finished, and the pieces are hung up to dry for at least twenty-four hours; after which they are rinsed thoroughly in cold water; and when they have been dried with care, they are properly calendered and put up for sale.

Nothing now remains but to notice an improvement which has been made of late years by the introduction of CYLINDER-PRINTING, which has the advantage of superior accuracy and neatness, as well as of great expedition [67].

The machines which effect this are rather complicated, and very expensive; but some kind of work cannot be produced at so cheap a rate by any other means. The plate which accompanies this Essay will afford a general idea of the nature of these machines; the construction of which may be thus further explained: They are so contrived that

[67] A vnriety of observations on the printing of calicoes by means of the cylinder, which may be read with advantage in connection with this essay, will be found in Nicholson's 4to *Journal*, vol. i. page 18.

the cylinders on which the patterns are engraved, furnish themselves with the prepared colour during their revolutions; their surfaces are kept clean by a steel knife, or *doctor* as it is called, passing over them the moment they have charged themselves with the thickened colour; and they have such a pressure given to them, either by means of screws or levers, which can be tightened or slackened at pleasure, that the whole cylinder is made to deposit its colouring matter with the greatest certainty and exactness on the cloth, while this rolls over it in succession, from one end of the piece to the other.

These cylinders, which are made of copper, are from eighteen to forty-two inches in length, according to the width of the calico to be printed, and three and a half to five inches in diameter; and these massy rollers have the patterns enchased upon their surfaces, in the same way as a pattern is cut upon a flat plate of copper, that is intended to be employed in copper-plate printing [68].

Many of these machines are contrived so as to carry two of these cylinders, each of which has a trough of colour attached to it, by which means two different colours may be printed on the same calico, at one and the same time; and Mr. Adam Parkinson of Manchester has invented a machine capable

[68] As these cylinders are made with plates of copper hammered into a circular form and joined by brazing, great loss has sometimes been sustained by the engraving giving way upon the brazed joint. To obviate this, a patent has been obtained for boring the copper cylinder from the solid metal in the modern way of boring cannon.

of printing at one time, by means of one cylinder and two surface rollers, or by two of the former and one of the latter, three distinct colours [69].

These machines have not only the excellence of printing more correctly than can possibly be done by means of the block, but the saving of time and labour which they afford is great indeed. A piece of calico which would take a man and a boy three hours to print with one colour, or six hours to finish with two colours, may by this means be printed in three minutes, or three minutes and a half, and the work will be much more completely done than could even have been imagined before the introduction of this invention.

Besides these cylinders there are others which are called SURFACE-MACHINES, which contain cylinders, not of copper but of wood, and which have the pattern formed upon their surfaces in relief, exactly similar to the blocks described in page 268. These are employed in particular styles, especially on light grounds [70], and for certain kinds of resist- and discharge-work.

It must be obvious to every one who is acquainted with the subject, what an astonishing facility these machines must have afforded to the production of printed calicoes; and also what an advan-

[69] See the plates, fig. 12.

[70] In light work, the white grounds are apt to be soiled by the cylinders: hence surface-machines were contrived, and these are not liable to the same objection. Cylinder-machines are more commonly employed in those styles which are full of colour and leave but little white.

tage they give to the British printer in foreign markets.

But I cannot conclude without expressing my fears, that even these facilities may eventually be the means of doing a serious injury to the trade, and of destroying that confidence in the goodness of British prints, which has hitherto been generally felt in every market on the continent, and also in every part of the New World, wherever they have been introduced.

I refer here to that mode of printing which has been adopted of late years, and which consists in precipitating the colouring matter from log-wood, and from other *fugitive* dyes, and in printing these on the cloth, without any mordant or previous preparation whatsoever. Many thousands of pieces of this sort are finished at the low rate of one halfpenny the yard, including every expense of colour, flour-paste, and printing. These articles, it will scarcely be credited, are dried up immediately from the printing machines, and are shipped abroad, without even being washed off [71].

Such goods, wherever they go, must produce great dissatisfaction, for they will neither endure the rays of the sun, nor moisture. The first shower of rain to which they may be exposed, will not fail

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[71] To *wash off*, is a technical phrase. It means the soaking and rinsing the pieces in water, in order to dissolve and remove the gum or paste which had been employed with the colours in printing them.

to wash out the pattern, and reduce them to a worse state than that of plain white calicoes.

In the reign of Queen Elizabeth, an Act was passed to restrain the use of log-wood [72] in dyeing, on account of the fugitive nature of its colour; and if this degrading kind of printing be continued, the interference of the Legislature will again become necessary, or the foreign trade will, from this cause alone, be entirely lost to the country.

I consider it to be my duty to advert to this practice at the conclusion of the Essay, and I shall have great reason to rejoice, should these observations be the means of averting such a calamity.

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[72] In the time of Queen Elizabeth the nature of logwood was not understood; but now it has many important uses, and when properly employed is one of the most valuable articles used in dyeing.

ESSAY V.

ON

BARYTES.

ESSAY V.

ON

BARYTES.

IN the year 1774, M. Scheele made some experiments on a mineral called *Marmor Metallicum*, which he found to be a combination of sulphuric acid and a peculiar alkaline earth not as yet described. Gahn also minutely examined this mineral in the year 1775, and both these chemists agreed to denominate the base of it "heavy earth." Scheele then published an account of his experiments upon it in a memoir on manganese, and this work directed the attention of most of the chemists in Europe to the investigation of its nature and properties [1].

Bergman at first called the earth *terra ponderosa*; Weigleb and Sage called it *barogium*; afterwards it was called *barotes*; and at last Bergman named

[1] See Dr. Hoepfner's paper on Sulphate of Barytes in Crell's *Annales*, tom. i. p. 132; or in *Annales de Chimie*, tom. i. p. 217.

it, from the Greek word "*barus* heavy," *barites*; and with the alteration of a single letter, it has borne that name ever since.

Barytes has never been found native otherwise than in combination with an acid. Its affinity for the carbonic and other acids is such that it cannot exist in nature in a state of purity.

The mineral on which the first experiments were made was a sulphate of barytes, the only native substance which was then known to contain this alkaline earth. This mineral, which has been called *vitriolated heavy earth*, *ponderous spar*, *phosphoric spar*, *baroselenite*, &c., occurs very plentifully in various parts of Great Britain, and in most countries of Europe. Its specific gravity is generally from 4,400 to 4,470. It is perfectly insoluble in water, and is the only barytic salt that is not poisonous.

This native production is found in large masses in the Derbyshire lead mines, where it is distinguished by the name of *cauk*; in the Cornish copper mines; at Roye in the province of Picardy in France; in the vicinity of Mount Etna, and in a variety of other places. It occurs in veins nearly four feet wide, traversing the sand-stone in the Isle of Arran, at a small distance from the shore. Also at Pomona in the Orkneys [2]. It is the heaviest native earthy salt with which we are acquainted.

It is composed of different proportions of acid,

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[2] See Jameson's *Mineralogy of the Scottish Isles*, 4to, 1800, vol. i. page 71, and vol. ii. page 232.

base and extraneous matter, according to its peculiar locality; whereas the sulphate of barytes which is formed by art consists of 66 barytes and 34 sulphuric acid[3]. The native sulphate is sometimes of a flesh colour, and of a foliated texture; but it occurs also in a great variety of crystalline forms and colours. Thus, very beautiful specimens of crystallized sulphate of barytes were formerly procured from the Nutfield fuller's earth pits, at Bletchingly near Godstone in Surry. The workmen found it generally in loose pieces in the midst of the bed of fuller's earth, and called it shining spar.

Besides the places already enumerated, beautiful specimens of the sulphate of barytes are found in some of the northern counties of England. In Mr. Hutton's museum at Keswick in the county of Cumberland, there is a single crystal which is perfectly formed, and weighs 29lbs. 2oz. When weighed hydrostatically it loses 6lbs. 1oz. and consequently its specific gravity is 4,8041. It will be perceived that this is a much greater specific gravity than has ever been ascribed to the sulphate of barytes, and I regretted that I could not confirm the fact myself; —but having no opportunity of weighing this stupendous crystal hydrostatically in the museum of Mr. Hutton, I could only copy the weights from the label affixed to it. This curious crystal was found near *Cross-fell* in the county of Cumberland.

[3] A method of analysing sulphate of barytes is described by M. Afzelius, of Upsal, in Crell's *Annales* for 1788, and in the *Annales de Chimie*, tome iii. p. 290.

A species of this mineral is found about the Apennine mountains, and in several other parts of Italy, in round pieces about the size of a walnut, of a light gray colour and uneven surface. These have often the shining appearance of some of the other species of sulphate of barytes; and after heavy showers of rain, which wash away the earth from the mountains, they are found in abundance[4].

These little nodules, which are called *Bologna stones*, and sometimes *Bonona stones*, are remarkable for acquiring a phosphorescent quality by calcination. Lemery relates, that this property was discovered by one Casciarolo, an Italian shoemaker, who picked up one of these stones at the foot of Mount Paderno, four Italian miles from the city of Bologna[5].

This man, imagining from its weight and colour that it contained silver, submitted it to calcination, to extract, as he thought, the precious metal: and though he was disappointed in this respect, he discovered that the action of the fire had given it the property of being luminous in the dark; and that not only this particular stone, but others[6], which he afterwards treated in a similar manner, acquired the same property[7].

It has been said that these stones retain their luminous quality even when laid under water[8]; that

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[4] Busching's *Geography*, 4to, vol. iii. page 139.

[5] See Homberg, *Philosophical Transactions*, No. 21.

[6] An account of a variety of phosphorescent bodies may be seen in the *Philosophical Transactions* for 1792, page 28, &c.

their splendour usually lasts three or four years, and that it may then be renewed by a fresh calcination[9].

I am not aware that the *native* sulphate of barytes is used at present for any other purpose than preparing the Bologna phosphorus, and for the extraction of pure barytes by means of charcoal and the nitrous acid. It was, however, pretty largely employed some years ago by that ornament of our country, the late Josiah Wedgwood, in the manufacture of his beautiful jasper ware, which rivalled the productions of antiquity, and found its way into the mansions of all the votaries of taste in every corner of Europe.

From this employment of the sulphate of barytes, Mr. Wedgwood, for a long time, derived great profit; none of the workmen having any idea of the nature of the material on which they were operating; until a letter, containing a bill of parcels of a quantity of the article, fell unfortunately into the hands of a faithless servant, who sold the secret, and deprived the worthy inventor for ever of that particular source of emolument. For, when the article was manufactured by those who employed inferior workmen, to whom they did not pay one-fourth of the salary which was given by Mr. Wedgwood, the

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[7] There is a paper on the preparation of the Bolognian stone in the *Philosophical Collections* for 1681, published by the Royal Society of London, page 77.

[8] See Busching, vol. iii. page 140.

[9] For the best method of making Bologna phosphorus, see Lagrange's *Manual of Chemistry*, vol. i. page 188.

price of jasper-ware became so reduced that it was no longer in Mr. Wedgwood's power to employ those exquisite modellers whom he had formerly engaged to superintend that branch of the manufacture.

The *artificial* sulphate of barytes has for many years been applied to the purposes of painting in water-colours, and it is the most delicate and perfect WHITE now in use. It was first recommended and brought forward by Mr. Hume, who has long supplied the public with it under the name of *permanent white*. I know of nothing so well calculated as this for marking bottles in a chemical laboratory, where the gases soon destroy the ink of common labels, and render them illegible. It is equally useful for marking jars, bottles, or boxes which must be kept in a damp cellar; for it is not only imperishable in such situations, but preserves its extreme whiteness, and consequently the distinctness of the characters.

Sir Humphry Davy says that the artificial carbonate of barytes, formed by pouring a solution of carbonate of ammonia into a solution of nitrate of barytes, also forms a pigment of a very pure white colour [10].

If the native sulphate of barytes, reduced to powder, be mixed with a large portion of charcoal, and submitted to a red-heat for several hours, the sulphate will at length be converted to a sulphuret of barytes, and the sulphur may afterwards be precipi-

[10] Davy's *Elements of Chemical Philosophy*, page 343.

tated by pyroligneous or acetic acid. The acetate of barytes may then be evaporated to dryness, and a moderate heat will dissipate the acid, and leave the barytic earth nearly in a state of purity.

The following direction is given by Mons. Brisson, the French professor of chemistry. "Pulverize," says he, "sulphate of barytes, and calcine it in a crucible, with an eighth part of its weight of charcoal dust; keep the crucible at a red-heat for about an hour, and then pour the matter into water: the water will assume a yellow colour, and exhale a strong odour of sulphuretted hydrogen gas: then filter the liquor, and pour into it muriatic acid: there will be formed an abundant precipitate, which must be separated by a second filtration. The liquor that passes through the filter holds in solution muriate of barytes, which is formed by the addition of the muriatic acid. If you then add liquid carbonate of potash, the potash will combine with the muriatic acid, and the barytes with the carbonic acid, from which it may be freed in a great measure by calcination: what then remains is for the most part pure barytes."

Another process has been described by La Grange: this consists in the mixture of muriate of lime with the barytic sulphate, which mutually decompose each other. The two salts are to be intimately mixed and fused in a crucible: the result will be sulphate of lime and muriate of barytes, which are to be separated from each other by means of water[11].

[11] For a more particular account of the process see the memoir itself, *Annales de Chimie*, tome xlvii.

Kirwan, who made many experiments on this peculiar earth, has published accurate descriptions of three distinct species of *native* barytic salts, viz. carbonate of barytes, baroselenite, or sulphate of barytes, and the liver-stone, or hepatic sulphate. The baroselenite, which we have been considering, he divides into five families, consisting of the loose, the compact, the foliated, the striated, and the acicular baroselenite [12].

Mr. Jameson divides the barytic minerals into five species, including the sulphate and carbonate of strontian, which belong to another family, and certainly ought not to be arranged with barytes. The true barytic salts he divides, like Kirwan, into three species, which he calls witherite, heavy spar, and hepatite.

The first of these is the native carbonate of barytes, which will be described hereafter; the second, or heavy spar, he divides into eight subspecies, viz. the earthy, the compact, the granular, the lamellar, the fibrous, the radiated, the columnar, and the prismatic heavy spar; and the last, known to modern mineralogists by the name of hepatite, is a compound of sulphate of barytes, uncombined sulphur, and several extraneous matters, and agrees with the mineral which Kirwan has described under the name of liver-stone.

Notwithstanding this great variety of barytic minerals, for nine years after the discovery of pure barytes by Scheele, the chemists of Europe were un-

[12] See Kirwan's *Elements of Mineralogy*, vol. i. page 134—143.

acquainted with any other source for the production of this alkaline earth, besides the ponderous spar of which we have been treating, until Dr. Withering, a physician of Birmingham, announced that among the minerals in Mr. Bolton's cabinet he had discovered a specimen of native carbonate of barytes, which was found in a lead-mine on Alston moor, in the county of Cumberland. This discovery was made in the year 1783, and the particulars respecting it were published in the Philosophical Transactions for the year 1784.

This mineral was first called *Witherite*, from the name of its discoverer, a gentleman well known to the literary world as the author of a useful treatise on botany, entitled "A botanical Arrangement of all the Vegetables naturally growing in Great Britain," 2 vols. 8vo; a work which has since been enlarged and much improved by Dr. Stokes, an eminent physician now living at Chesterfield in Derbyshire.

Soon after its discovery, this mineral acquired nearly as many names as those of the persons who wrote upon it, as *mephite* of barytes, *chalk* of barytes, *aërated heavy earth*, *aërated baroselenite*, *aërated ponderous spar*, &c. &c.; and then Lavoisier named it *carbonate of barytes*, which is an appropriate term, and that which it has borne ever since.

Not long after this discovery of Dr. Withering's, it was found that a similar mineral existed in abundance in the lead-mines of Anglezark in Lancashire;

and while these mines were worked, the chemists of Europe might have been supplied with any quantity of this native carbonate at a small expense; and according to Leigh, who wrote the history of Lancashire, these mines abound also in sulphate of barytes [13].

Since the discovery of carbonate of barytes at Anglezark, a similar mineral of various degrees of purity has been found at Aldstone in Cumberland; at Dufton and other places in the county of Durham; at Merton Fell in Westmorland; and at Snailback mine in Shropshire. I have heard that it has also been discovered in one particular district in Scotland, and also in Sweden; but Guyton and Carny in the 19th volume of the Annales de Chimie tell us that at that time it had not been discovered in any part of France.

Carbonate of barytes is found crystallized; and according to Thomson and Jameson, the crystals have been observed to assume four different forms, viz. double six-sided and double four-sided pyramids; six-sided columns terminated by a pyramid with the same number of faces; and small radiated crystals half an inch in length and very thin, appearing to be hexagonal prisms rounded towards the point.

The massive varieties occur in thin wedge-shaped distinct concretions, which are often very much grown together; and occasionally they pass into

[13] Leigh's *Lancashire*, fol. Oxford, 1700, page 71.

coarse granular masses. The crystallized carbonate of barytes is translucent, though but rarely semi-transparent. Its colours are greyish and yellowish white; also pale wine-yellow; and not unfrequently of a pale flesh-red. It slightly decrepitates before the blow-pipe, and melts readily into a white enamel. It is soluble with effervescence, in diluted muriatic or nitric acid, and may thus be distinguished from sulphate of barytes, which is insoluble in both these acids. Its specific gravity is 4.33; though when prepared artificially it scarcely exceeds 3.76. It has no sensible taste, and yet it is an active poison. It is very sparingly soluble either in cold or hot water; and is not altered by exposure to the air. By peculiar management it may be decomposed when submitted to an intense heat.

The native carbonate of barytes found at Anglezark consists of 22 parts of carbonic acid, and 78 of barytes; and the factitious carbonate is a similar compound. Pelletier says that he analysed some native carbonate, and found it composed of 22 parts of carbonic acid, 62 parts of barytes, and 16 parts of water; but I apprehend this account is erroneous.

Those who have done most in investigating the nature of this earth, since the discovery by Dr. Withering, are Pelletier above mentioned, Vauquelin, and Fourcroy in France; and Professor Hope of Edinburgh. The French chemists published an account of their experiments in the Annales de Chimie for the year 1797; but Dr. Hope had published his valuable paper in the Edinburgh

Transactions four years before this[14]. It is, however, generally acknowledged that, before these eminent chemists undertook the series of experiments in which each of them was engaged, pure barytes was not known.

At one time no carbonate of barytes was found any where in these kingdoms, except in the lead-mines of Anglezark in the hundred of Salford in the county of Lancaster. Conceiving that this mineral product might probably be usefully employed in some of our manufactures, if an abundant supply could be procured, I determined to go to the mines to make the necessary inquiries; which I did in the autumn of 1810.

On inquiring at Chorley, I found that the mines are in the midst of the moors, at a considerable distance from any turnpike road, about eight or nine miles from the town of Bolton, and three from Chorley; and in so obscure a part of the country that it would be necessary for me to take a guide with me; and I was so fortunate as to meet with a gentleman in the town, who very kindly offered to accompany me and conduct me thither.

From the town of Chorley you go about a mile on the road to Bolton, and then turning off to the right, proceed through a very rough stony lane, which brings you near to the village of Limbrick, which is about two miles from Chorley; and then

[14] See *Annales de Chimie*, tom. iv. page 62; tom. xxi. pages 113 and 276; and the *Edinburgh Transactions*, vol. iv. p. 36.

passing over some romantic fields, you arrive at the house of Banister Derbyshire, a fine old man of seventy years of age, who occupies the estate in which the mine is situated.

This man, who knows more of the history of these singular mines than any one in the neighbourhood, walked with us to the spot, and showed us the places which were formerly occupied for the different purposes connected with the working of the mines.

From him I learnt that all these are *lead*-mines, which were in full work more than a hundred years ago; and that they were again opened, long before his time, by Sir Thomas Standish, the father of the present proprietor.

From the appearance of the land, it is evident that there have formerly been a great number of shafts for drawing up the minerals; and on making inquiry as to this point, our guide informed me that he was sure he could find forty at the least; whence I conclude that a large quantity of lead ore must some time or other have been raised.

About forty years ago these mines were worked a third time by the direction of Sir Frank Standish, who drove fresh levels from the foot of the several hills, into the heart of the mine, in order to carry off the water, and enable the men to work: but having engaged several different sets of workmen, who all conspired to defraud him of their time, and endeavoured to impress his mind with an idea of the small quantity of ore that could be procured,

at the moment when they were practising various arts to induce him to lease the mine to them, he became tired of mining; and about the year 1790, when he had sunk some thousands of pounds in the undertaking, the work was again discontinued, and all the miners dismissed.

It is apparent that this proprietor had no idea of working these mines again, for every thing about them has been allowed to go to ruin. Our guide showed us where stood the large water-wheel for winding up the water from those parts of the mine that could not be drained by the levels; which was the site of the warehouse for storing the washed ore; and where stood the smithy for repairing the tools of the workmen: but there is now scarcely a square yard of walling belonging to any of these buildings left standing entire.

Knowing that we are all the victims of habit and the creatures of circumstance, I could not help fancying, while exploring this forsaken domain, what a different character the proprietor of these mines might have been, had he been fortunate enough in his youth to receive a liberal education, and to imbibe a taste for literature and science: for, had this been the case, he might now have been as eminent for the accurate investigation of the treasures which nature has hidden within his most valuable estate, and for other useful and scientific pursuits, as he has been, through a long life, for his skill on the turf at Newmarket [15].

[15] Sir Frank Standish died since this Essay was written; and

The quantity of carbonate of barytes in these mines is immense, much greater, I understand, than that of the lead ore (five to one, as our guide supposed); but as the metallic ore was raised, this was always left behind in the mine, being considered of no value. The workmen called it spar.

Some of the best-informed people in the town of Chorley say, that the first time any idea was given of the value of this spar, was by the arrival of two Frenchmen about the year 1782. It seems that they were in the town some days without the nature of their business being suspected, till it was at last discovered that they had been at the lead-mines, and had filled two boxes with the spar, which they secured with great care, and sent off by the carrier before they left the town.

At this, Mr. Tatham, the steward of Sir Frank Standish, immediately took an alarm; and having given strict orders that in future no one should be suffered to take away any of the spar, set himself to make every inquiry he could into its nature; to learn, if possible, to what uses these foreigners intended putting it; and whether some methods might not be discovered for consuming it in this country. In prosecuting these objects of inquiry, however, he never succeeded.

The papers by Dr. Withering in the Philosophical Transactions, on the carbonate of barytes, and Dr. Crawford's on the muriate of this earth, had

it was expected that the valuable estate, including the mines of Anglezark, would devolve to a youth then about 12 years of age.

now drawn the attention of all the chemists of Europe to this newly discovered mineral; so that its real nature and properties were every where soon understood. But during this investigation, in which every chemist who was fortunate enough to procure specimens was probably engaged, nothing new occurred at the mine or in the neighbourhood respecting it, till it was discovered that a man of the name of Smithels, who occupied a cottage and about forty acres of land under Sir Frank Standish, close to the mines, had long been engaged in disposing of the carbonate of barytes in an illicit manner.

This man, who was well known in the neighbourhood of Chorley, and is still remembered by many of its inhabitants, used to get the spar from among the heaps of stone and rubbish that lie round the mouths of the old shafts. This he used to pack in strong boxes, and delivered them himself, by his own cart, to the carrier in Chorley, to be conveyed to Liverpool.

He managed this business so well, that he not only bought the boards for making the boxes, but prepared the boxes himself in the night, and suffered no one to see him pack the article, or carry it away when packed. Besides, it went from Chorley by the common carrier to a broker in Liverpool, who shipped it to a middle-man upon the continent;—so that the place where it was actually consumed could never be traced out.

A neighbouring farmer had, indeed, for some years observed that James Smithels was often en-

gaged in picking something from off the waste land; and that often on moonshine nights, when they imagined no one observed them, he and his wife were employed for hours together upon the mounds which stand round the old shafts; and on the circumstance being mentioned to the steward of Sir Frank Standish, he put an entire stop to this poor man's little trade.

However, when he was questioned by the steward, and by a variety of other persons, respecting this transaction, he remained sullen and silent, and would never give them the least information as to the quantity he had sold, the price he had obtained for it, or even to what part of the world it went. It was, however, imagined that the two foreigners before mentioned were the people who had engaged this man to collect it, and that they had found some means of regularly paying him for what he procured for them.

As the quantity of carbonate of barytes thus collected, was much larger than could be employed merely for the preparation of chemical tests, and for a few common purposes of philosophical research, I was desirous of ascertaining something more, if possible, respecting this traffic in the Anglezark spar; and from one Alexander Gerrard [16], an intelligent farmer, who resides not far from the mine, and was formerly very intimate with the aforesaid James Smithels, I learnt the following particulars:

[16] I have entered upon this detail, and given the names of these men, in order that, if any persons should wish to prosecute the inquiry, they may know to whom to apply for information.

That Smithels, only a short time before his death, informed Gerrard that, in the whole, he had sold a very large quantity of the spar; that he received five guineas per ton for it; that it went from Liverpool to some part of Germany; and that he had understood, from the person who usually paid him, that it was consumed in some process in the manufacture of porcelain [17].

Being desirous of knowing whether these poor uneducated men had any idea of the nature and properties of the carbonate of barytes, I put some questions to them for that purpose. They told me, all they knew of it was, that it was a strong poison.

When I endeavoured to ascertain the extent of their knowledge on this subject, Mr. Derbyshire assured me that some years ago, he lost some cows, who had strayed from their pasture, and were found licking the lumps of spar which at that time lay about the mine in abundance; and that on opening one of these animals, several small pieces of spar were found in its stomach.

He told me also, that it was impossible to keep any fowl upon the farm; for, mistaking the smaller pieces of the spar for white sand, they were sure to pick it up, and die immediately. Ducks and geese, he says, he can keep, as they do not swallow it, ex-

[17] This circumstance has induced me to write so full an account of this transaction, in the hope that some of our manufacturers of earthenware will be tempted to persevere with experiments on the native carbonate of barytes, till they discover an advantageous method of employing this mineral in some branch of their manufactory.

cept at the time they lay their eggs, and then they never fail to take it, and with the same baneful effect. Doubtless they mistake it for lime or chalk, which all oviparous animals are obliged to swallow at the time of their laying, in order to shell their eggs. For if fowls be pent up in a situation where they are deprived of all calcareous matter, it is well known that they lay their eggs without shells.

It has been doubted whether the carbonate of barytes be a poison to the human species; but on examining Leigh's History of Lancashire, written more than a century ago, to see if these mines were noticed by him, I find the question answered in the affirmative [18].

Mons. Fourcroy, when examining the question, whether the carbonate of barytes be a poison, or not, says, "There is every reason to believe that pure barytes is a violent poison, since when combined with the carbonic acid, and having lost all its acrid taste by this union, it speedily poisons animals. Mammiferous animals which have been made to take it, have experienced acute pains, convulsions, vomiting, and death. Their stomach and intestines were inflamed, spotted, sphacelous, and even, as it were, in some parts corroded: its administration in medicine must, therefore, require great caution [19]."

"Messieurs Huzard and Biron gave to some

[18] Leigh's *Natural History of Lancashire*, folio, Oxford, 1700, page 70.

[19] Fourcroy's *General System of Chemistry*, vol. ii. p. 273.

horses the muriate and carbonate of barytes, in doses of 118 grains English, every day; and these animals died suddenly after having taken them for a few days." "A dog, which Pelletier caused to swallow 20 grains, was seized with vomiting, and died within eight hours afterwards [20]."

In consequence of the various accidents which occurred in Lancashire after the opening of the Anglezark mines, this spar in the district where the mines are situated, has obtained the name of *rats-stone*.

Pelletier relates, that the Society of Health at Paris was engaged in ascertaining what advantages medicine might derive from the use of barytes; and that both the muriate and carbonate of this earth were given to horses seized with that highly infectious disease called the *farcy*, for which corrosive sublimate is generally administered; and he adds, that both these medicines given to two different horses, in the quantity of two drachms a day, seemed for a while to have effected such a change that they were even considered as cured at the end of a fortnight, but nevertheless they both died within a few days of each other [21].

Dr. Withering observed the difficulty there is in decomposing the native carbonate of barytes, and

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[20] Chaptal's *Chemistry applied to the Arts*, vol. ii. page 70. Nicholson's *Journal*, vol. i. 4to, page 529.

[21] *Annales de Chimie*, tom. xxi. page 113, or Nicholson's *Journal*, 4to, vol. i. page 529.

that when submitted to a strong heat it sooner fuses than parts with its carbonic acid. But Dr. Hope announced[22], that when he submitted it to an intense heat in a black-lead crucible, the carbonic acid was separated, though in an earthen crucible nothing was permitted to escape, and consequently no decomposition was effected. In considering this result, Pelletier was induced to try the effect of mixing it with charcoal before he heated it, and by this means he obtained barytes tolerably pure and soluble.

M. Fourcroy, who has related this circumstance, confesses that the theory of the experiment is unknown to him[23]; but may it not be attributed to the charcoal combining with the carbonic acid of the carbonate of barytes, and with it forming carbonic oxide[24], which is a gas somewhat lighter than atmospheric air, and very highly combustible?

If, however, barytes perfectly pure be required, it can only be obtained by dissolving the native carbonate, or the artificial sulphuret of barytes procured according to the directions given at page 319, in diluted nitric acid; in evaporating the solution, either to dryness, or the point of crystallization, and then decomposing this salt by heat. The process in detail may be thus described:

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[22] Dr. Hope published his experiments in the year 1793, in the *Edinburgh Transactions*, vol. iv. page 36.

[23] Fourcroy's *System of Chemistry*, vol. iv. page 14.

[24] Carbonic acid contains only 27.4 per cent. of carbon; but carbonic oxide contains nearly 43 per cent.

The mineral (the sulphate or the carbonate) is first to be reduced to powder, and intimately mixed with about one-fourth of its weight of ground charcoal. It is then to be put into a crucible and submitted for an hour to the action of a red heat, well covered with charcoal to secure it from the access of atmospheric air. This treatment, if the sulphate be operated upon, will convert the sulphate of barytes to a sulphuret, which is to be dissolved in water and the impurities suffered to subside. The clear solution is then to be treated with nitric acid, which will combine with the barytes and occasion the sulphur to precipitate. The newly formed nitrate of barytes is now to be slowly evaporated, until the salt crystallizes; and then, if the salt be exposed in a crucible to a gradual heat, to separate the remaining water, and afterwards to a stronger heat, sufficient to expel the whole of the nitric acid, pure barytes will remain, which should be quickly removed to a stoppered bottle to prevent its absorption of carbonic acid.

Barytes is an oxide of barium, and possesses the following properties:—When pure, it is of a greyish white colour, and is so porous that it may very readily be reduced to powder. It consists of 1 proportional of barium = 65 + 1 proportional of oxygen = 7.5, and consequently in the table of equivalents is represented by 72.5. Its specific gravity is about 4. When exposed to the air, it changes rapidly; it swells like quicklime, and, like it, falls into a white powder; but this slacking is

much more violent and speedy than that of lime. In this process it combines so intimately with the water of the atmosphere, which it solidifies, that it will not part with it even at a red-heat. In this state it is called the hydrate of barytes, and consists of 1 proportional of barytes = 72.5 + 1 proportional of water = 8.5 : consequently we say the hydrate of barytes is represented by 81.

If the hydrate of barytes be dissolved in boiling water, and the solution suffered to cool, crystals containing a still larger proportion of water will be deposited. These crystals, white and transparent, generally appear in the form of hexagonal prisms, considerably flattened, and have been found to consist of 1 proportional of barytes = 72.5 and 20 proportionals of water = 8.5 × 20 or 170 water; so that the crystallized hydrate must be represented by 242.5.

These crystals are sometimes long four-sided prisms, terminated at each extremity with a four-sided pyramid. Sometimes they are attached to each other in a peculiar way, and sometimes the crystallized salt precipitates in the liquor in the form of cubes. The crystals of barytes require more than 17 times their weight of water for solution. According to Mr. Dalton, if these crystals be exposed to the air, they will effloresce and fall into a white powder, consisting of 1 proportional of barytes and 5 proportionals of water[25]. Hence it seems that

[25] Dalton's *New System of Chemical Philosophy*, page 523.

there are at least three distinct hydrates of this earth: viz.

1st hydrate consisting of	72.5 barytes +	8.5 water =	81
2nd hydrate	72.5 barytes +	42.5 water =	115
3rd hydrate	72.5 barytes +	170.0 water =	242.5

Barytes has, however, several other properties which must be enumerated. It has a harsh and pungent taste, and is more caustic than quicklime; it has no smell whatever, but when taken into the stomach acts as a most corrosive poison. It is very difficult of fusion, but when strongly heated on charcoal before the blow-pipe, it melts into a grey opake mass. Like the alkalies, it changes the vegetable blues to a deep green; the red to a violet or blue; and the yellow vegetable colours, such as turmeric, &c. to a brown. It is also similar to the alkalies in being itself a metallic oxide; in its rendering oils miscible with water; in forming glass when fused with silica; in its solubility in water; and in its capability of dissolving some of the other metallic oxides.

It is soluble in about 20 parts of water at the temperature of 60°; but boiling water will dissolve half its weight of this earth, part of which, as has been already mentioned, will crystallize on cooling. It absorbs carbonic acid from the atmosphere, and has so strong an affinity for sulphuric acid, that it will not part with it even to pure alkalies. Hence it has the property of decomposing sulphate of potash, or sulphate of soda. Barytes is unalter-

able by light: it is a non-conductor of electricity; and when dissolved in water, or in certain acids, furnishes excellent tests for chemical analysis. It is also capable of making a very tenacious cement. When strongly heated in oxygen gas, or if oxygen gas be passed over red-hot barytes, the oxygen will be absorbed, and the barytes will be converted to a grey substance, which may be called the *peroxide of barium*, consisting of barium 65 and oxygen 15 = 80; or it may be stated thus: barytes 1 proportional = 72.5 + 1, additional proportional of oxygen 7.5 = 80. Barytes may be known from all the other earths, by its superior solubility in water; by its forming an insoluble compound with sulphuric acid; and by its imparting to flame a yellow colour.

When speaking of the native carbonate of barytes, I should have remarked, that neither nitric nor muriatic acid, when concentrated, has any effect in dissolving carbonate of barytes, as was first shown by Fourcroy [26]. This chemist was, however, mistaken in asserting that barytes "forms with *all* the acids the most permanent compounds, and the most difficult of all to be decomposed," since it is true only of those acids which form with barytes *insoluble* salts; for, if this earth be employed to decompose common salt, it only produces a partial decomposition, and may be precipitated again from the acid, by means of either of the carbonated fixed alkalies [27].

[26] *Annales de Chimie*, tom. iv. page 62.
[27] *Ibid.* tom. xlix. page 95. Nicholson's *Journal*, vol. xviii. page 68.

It has already been observed that the chief use which has hitherto been made of barytes, has been in the preparation of certain tests for chemical analysis; and as these are of the utmost importance to every analytical chemist, I shall now proceed to give an account of the methods of preparing some of the most valuable of these tests. Those in common use are, the nitrate, the muriate, and the acetate of barytes; and not unfrequently a solution of pure barytes in distilled water.

By copying the particulars of a few of these processes from my common-place-book, where they stand as they were entered at the time of making the experiments, I shall be in no danger of misleading the reader.

Process for Nitrate of Barytes.

	lb.	oz.
Nitric acid spec. grav. 1.250	2	0
Distilled water	8	0

When cold, the mixture had the specific gravity of 1.0528.

To this diluted acid one pound of the native carbonate of barytes was added, and the whole submitted to a gentle heat. The acid dissolved the barytes with rapidity; but when the action had ceased, a large portion of residuum, which was chiefly nitrate of barytes in a crystallized state, was found in the vessel wherein the solution had been made. To dissolve this nitric salt more water was added by degrees, until sixteen pounds were employed; when the only residuum remaining was one ounce of the carbonate of barytes, which the nitric acid

was incapable of taking up[28]. The materials used, and the amount of the produce, then stood thus:

	lb.	oz.	
Nitric acid . . .	2	0	at 1.250
Water	24	0	
Carb. baryt. . . .	0	15	
	26	15	

Produce.	lb.	oz.
Sol. nitrate barytes sp. gr. 1.0507	22	6
Loss by evaporation and by the disengagement of the carbonic acid	4	9
	26	15

Finding that so large a portion of water is necessary for holding the nitrate of barytes in solution, I have since adopted a different process.

A better Process for Nitrate of Barytes.

	lb.	oz.
Nitric acid spec. grav. 1.250 . . .	2	0
Pure water	24	0

When cold, the mixture had the specific gravity of 1.0156.

To this diluted acid I added 19oz. of the native carbonate of barytes; and though the acid was so very much diluted, it immediately acted upon the earth and dissolved it rapidly, even in the cold. When submitted to a gentle heat, the solution went

[28] Some years ago Mr. Hume noticed that the nitrate and the muriate of barytes are entirely *insoluble* in the respective acids of which they are formed. This, however, is not the case with the sulphate of barytes, for that salt is perfectly *soluble* in its own acid. *Phil. Mag.*

on with still greater rapidity, and in about an hour the whole was dissolved. The produce was as follows:

	lb.	oz.
Sol. nitrate barytes sp. gr. 1.0600	22	14
Loss by evaporation and by the disengagement of carbonic acid	4	5
	27	3

It will be observed that there is not only less trouble, but an economy, in thus diluting the acid, as it prevents in some measure the loss of a part of the acid in consequence of too rapid an action. To obtain the nitrate of barytes in a state of purity, the solution should be evaporated to dryness, and the dry salt redissolved and crystallized. The crystals are permanent octahedrons, which sometimes adhere to each other in the form of stars. At other times the crystals are obtained in small plates[29], whose specific gravity is 2.9149. The taste of this salt is hot and astringent. It is soluble in twelve parts of water at 60° and in four parts of boiling water. When submitted to a red heat, the whole of the acid flies off, and pure barytes remains in the crucible. The nitrate of barytes is a very convenient test for many purposes, and especially for detecting the adulteration of nitric acid by the addition of sulphuric acid: but in this case it is absolutely necessary to dilute the suspected nitric acid very considerably with distilled water previously to the application of the test; otherwise, a

[29] Hassenfratz *Annales de Chimie*, xxviii. 12.

portion of the barytic salt is apt to precipitate, merely in consequence of the nitric acid abstracting part of the water which held it in solution, and this will occasion deception.

The dry salt consists of 1 proportional of barytes 72.5 + nitric acid 50.5 = 123. The proportions per cent. are,

Barytes	59
Nitric acid . . .	41
	100

The crystals of nitrate of barytes consist of

1 proportional of dry nitrate	123
2 proportionals of water	17
	140

If taken per centum, the proportions are,

Dry nitrate of barytes	87.85
Water	12.15
	100.0

In preparing the muriate of barytes, I have generally used very weak muriatic acid of the specific gravity of 1.0612. Such acid may be formed by mixing muriatic acid at 1.170 with double its weight of pure water. In this menstruum I dissolve the native carbonate of barytes to the point of saturation. Twenty-four pounds of this diluted acid are capable of dissolving exactly six pounds and a half of the native mineral; and the solution of the muriate of barytes which results from the process will be of the specific gravity of 1.260.

It did not occur to me, or I would have mentioned in an earlier part of this essay, that in calculating

the equivalent numbers of bodies, it is most convenient to make hydrogen, which is the lightest substance we know of, *unity*, and oxygen 7.5, because oxygen unites with hydrogen in the proportion of seven and a half of oxygen to one of hydrogen, to form water. The equivalent numbers throughout these volumes are all deduced from this basis.

The muriate of barytes, or chloride of barium, in a state of dryness is composed of

1 proportional of barium 65 + 33.5 chlorine = 98.5

or, barium 65.98 + 34.02 chlorine = 100.

This salt commonly crystallizes in tables; but according to Dr. Crawford it sometimes appears in the form of two eight-sided pyramids applied base to base. The salt is unalterable in the air, and not decomposable by heat [30].

The poisonous nature of barytes, in which it differs from all other earths, has been mentioned; but its most distinguishable property is the facility of its crystallization when dissolved in water, and which decidedly marks it to be very different from lime, which is sparingly soluble in water, and does not form crystals when it separates itself therefrom. Notwithstanding this, Margraaf asserted that the base of ponderous spar is calcareous earth; misled, doubtless, by its affinity for sulphuric acid, and by some other properties in which it does actually resemble lime [31].

[30] Dr. Crawford has expressly written on the properties of the muriate of barytes. His paper is in the second volume of the *London Medical Communications*, page 301.

[31] See Bergman's *Dissertation on Elective Attractions*, p. 180.

At one time strontites was confounded with barytes, and many chemists were at a loss to know whether there was any real difference between the two minerals; but an important series of experiments made by Pelletier, in the year 1796, has put this matter beyond all doubt, and established them as two distinct substances [32].

There are certainly many points of resemblance between barytes and strontites, such as their being both found native, and only in the state of combination with sulphuric and carbonic acids,—these native productions are also decomposable by similar means,—both sulphates are nearly insoluble in water, and yet soluble in an excess of sulphuric acid,—both carbonates are soluble in diluted muriatic or diluted nitrous acid, and neither of them is precipitated by pure ammonia.

There are, however, so many differences, and those so distinctly marked, that no chemist can now easily mistake the one earth for the other. The mention of a few particulars will be sufficient. Strontites has less attraction for acids than barytes; hence the salts of strontites are decomposable by barytes: strontites requires much more of any acid for its saturation than barytes does; the salts formed by the two earths are different in form and in the

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[32] The paper which gave an account of these experiments was read before the National Institute, April 30th, 1796; and afterwards published in *Annales de Chimie*, tome xxi. page 113, &c. A translation of it may be seen in Nicholson's *Journal*, 4to, vol. i. page 518.

rate of their solubility in water: for instance, muriate of barytes, as has been already mentioned, crystallizes in plates; whereas muriate of strontites gives slender hexagonal prisms. Moreover, pure barytic earth does not require one-tenth of the quantity of water for its solution that strontites does; and lastly, if strontites, or the salts formed with it, be dissolved in or mixed with alcohol, the spirit will burn with a flame of the colour of *carmine*; whereas barytes, as has been noticed already, gives a bright *yellow* colour to flame.

Water at the temperature of 50° takes up about a twenty-fifth part of its weight of barytes in its caustic or pure state; the solution remains transparent and colourless, and is known in the laboratory of the chemist by the term *barytic water*. It is necessary to keep it in bottles well closed, otherwise the earth will acquire carbonic acid from the atmosphere, and separate itself from the water of solution, as lime does in similar circumstances.

The best method of preserving barytes in a state of purity, is to dissolve it in warm distilled water; and if, during the heat that is generated by the slacking of the earth, the water be saturated with it, an abundance of crystals will be procured when the whole has become cold. These crystals should be kept in well stopped bottles, for the purpose of making barytic water as it may be required. It is extremely useful as a chemical reagent for discover-

ing the presence of sulphuric acid, and for other purposes.

An Acetate of barytes has also been found to be a convenient preparation of this valuable earth. This may be readily made by dissolving the native carbonate to saturation in acetic acid, when, by spontaneous evaporation, the solution will deposit very beautiful prismatic crystals of acetate of barytes, which will not deliquesce in the atmosphere.

When I first made acetate of barytes in quantity, I proceeded thus:—To twelve pounds of acetic acid of the specific gravity of 1.0420 I added three pounds of the native carbonate of barytes, and submitted the vessel containing it to a gentle heat. I found that, to dissolve the carbonate of barytes in acetic acid, it is only requisite to have the acid a little warm; 90° of Fahrenheit will be quite sufficient, until the acid approaches the point of saturation, and then it will be advisable to give it the heat of 130°.

When the action had ceased, and the whole become cold, I poured the solution from the residuum, and found a large portion of crystals of acetate of barytes among the carbonate which remained undissolved. Two pounds of water, however, were found sufficient to dissolve these crystals; and when the whole of the solution was filtrated, and the residuum carefully dried, twelve ounces of the original carbonate of barytes remained; so that

the materials used and the produce obtained stood thus:

	lb.
Acetic acid	12 at the sp. gr. of 1.0420
Water	2
	14
Carbonate of barytes	2¼
	16¼

Produce.	lb.
Sol. acet. barytes at 1.1870	13
Loss by evaporation	3¼
	16¼

If the two pounds of water had been added to the acetic acid in the first instance, the specific gravity of the mixture would have been 1.0380.

Finding that the acid which I employed was capable of dissolving more barytes than it could afterwards hold in solution, I have since adopted the following process, which I recommend as the best that I have been able to discover for making the acetate of this earth:

	lb.
Take Acetic acid at 1.0420	12
Pure water	12
Native carbonate of barytes well washed	2½
	26½

The produce will be	lb.
Sol. acet. baryt. at 1,1480	21
Probable loss by evaporation	5½
	26½

The specific gravity of equal weights of acetic

acid and water, when mixed, will be 1.0260; therefore acetic acid, which may originally be of a strength about equal to this specific gravity, will be very proper for the process.

The acetate of barytes has a sour and rather a bitter taste; it is soluble in water, and effloresces in the atmosphere. Its specific gravity is 1.8. It is decomposable by the fixed alkalies, which seize the acetic acid and precipitate the barytes. Most of the soluble sulphates also decompose it; and on this account it is constantly employed to detect sulphuric acid, or the sulphuric salts in solution. One hundred parts of water at the temperature of 60° dissolve 88 parts of the salt; boiling water dissolves nearly its own weight. It is composed of barytes 72.5 + acetic acid 48 = 120.5; or barytes 60.16 + acetic acid 39.84 = 100.

Whether the barytic salts are used in medicine, or as chemical reagents, it is of the utmost consequence to have them made uniformly the same. I have therefore thought it worth while to give these experiments in detail, in order to furnish, by means of the specific gravity, a standard for each of these solutions; so that those who may have occasion to employ the nitrate, the acetate, or the muriate of barytes, may know how to procure a solution that will always contain the same proportion of barytic earth.

The other salts that have been formed with barytes are the following, which I have arranged al-

phabetically, for the sake of greater facility of reference.

Antimoniate of barytes. This is a white powder, which may be obtained by mixing muriate of barytes with antimoniate of potash. It is perfectly insoluble in water. It is a light flocculent precipitate, which does not adhere to the sides of the vessel. It is not decomposed by exposure to the air, but the nitric acid extracts by digestion all the barytes[33]. It is probably composed of one atom barytes, and one of antimonic acid.

Antimonite of barytes. If a boiling solution of antimonite of potash be let fall drop by drop into a boiling solution of muriate of barytes, the antimonite of barytes crystallizes gradually on the tube in the form of small white needles of a silky brilliancy. These are slightly soluble in water, and unalterable in the air[34]. The salt consists of one atom barytes and one of antimonous acid.

Arseniate of barytes may be formed by mixing arseniate of potash with muriate of barytes, which produces an insoluble arseniate of this earth. It is in the form of a white powder, which is not decomposable by heat. It was first formed by Scheele, by dissolving pure barytes in arsenic acid[35]. Supposing this salt to be a compound of 1 atom of barytes and 1 atom of arsenic acid, its equivalent numbers will be, barytes 72.5 + arsenic acid 66.5 = 139.

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[33] Berzelius in *Nicholson's Journal*, vol. xxxv. page 40.
[34] *Ibid.* page 45.
[35] Laugier, *Annales de Chimie*, tom. lxxxv. page 58.

Arsenite of barytes is formed, like the foregoing, with arsenious acid. It is a white insoluble powder[36], composed of one proportional of barytes 72.5 + 1 of arsenious acid 59 = 131.5.

Benzoate of barytes is soluble in water, and crystallizable. It may be decomposed by heat, but is unalterable in the air. It is a compound of barytes 72.5 + benzoic acid 112 = 184.5.

Boletate of barytes. This salt contains an excess of acid, crystallizes in white plates, and is but little soluble in water, or even in nitric acid. When thrown on a plate of red-hot iron, it burns with a red flame and remarkable scintillation, leaving carbonate of barytes as a residuum[37]. Braconnot in the year 1811 discovered the boletic acid, and to that chemist we are indebted for the chief of what we know respecting the salts which have been formed by its means[38]. The acid is procured from a species of agaric, the *Boletus igniarius* of Linnæus, a fungus so called in consequence of its being frequently used for the purpose of tinder. The boletate of barytes is probably composed of one atom of barytes and one of boletic acid.

Borate of barytes is a white powder insoluble in water. It is prepared in a way similar to that of the other earthy boracic salts. It is a compound of 72.5 barytes + 20 boracic acid = 92.5.

Camphorate of barytes may be prepared by mix-

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[36] Laugier, *Annales de Chimie*, tom. lxxxv. page 58.
[37] Thomson's *System of Chemistry*, ii. p. 480.
[38] *Annales de Chimie*, lxxx. 279.

ing camphoric acid with a solution of pure barytes, and boiling the mixed solution to the point of crystallization. When the evaporation is conducted slowly, the salt is deposited in thin lamellar crystals, which appear transparent while immersed in the liquor, but become opake when exposed to the air. The salt has but little taste, though it leaves at last upon the tongue a slight impression of acidity mixed with bitterness. When exposed to heat it melts easily, and the camphoric acid is volatilized. When the heat is considerable, the acid burns with a lively *blue* flame, which becomes afterwards *red*, and at last *white*[39].

Carbonate of barytes. The artificial carbonate is similar in its nature to the carbonate which is found native, and has already been described at large, page 320—333. It is a compound of 78 parts of barytes + 22 parts of carbonic acid = 100.

Chlorate of barytes may be formed by passing chlorine gas into a solution of pure barytes. The salt crystallizes in quadrangular prisms, and is soluble in about four times its weight of water, at the temperature of 60°. The discoverer of chloric acid, M. Gay Lussac, first procured it from this salt by acting upon it with sulphuric acid. It is a compound of one proportional of barytes 72.5 + one of chloric acid 71 = 143.5.

Chromate of barytes may be formed by adding

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[39] Bouillon Lagrange, *Annales de Chimie*, xxvii. page 28. Thomson's *System*, ii. page 480.

chromate of potash to a solution of muriate of barytes. It is a yellow insoluble powder. Vauquelin has written the most on the chromates, in an essay printed in the 70th volume of the *Annales de Chimie*. According to him the salt consists of 62.2 barytes +37.4 chromic acid=99.6.

Citrate of barytes. When barytes is added to a solution of citric acid, a flaky precipitate appears, which is at first dissolved by agitation, but remains permanent when the saturation is complete. The citrate of barytes thus formed, is precipitated in the state of a white powder, but it gradually assumes the appearance of silky flakes, or forms a kind of vegetation very brilliant and beautiful. It requires a great quantity of water to dissolve it. According to Vauquelin[40] it is composed of 50 of the crystallized acid and 50 of barytes, which is nearly equivalent to one proportional of the earth 72.5 +55.5 acid =128.

Fluate of barytes is in the form of white flocks, insoluble in water, but soluble in an excess of fluoric acid. According to Dr. Thomson, this compound is a fluoride of barium, composed of fluorine 100, barium 437.5.

Formate of barytes. This salt is obtained in permanent crystals, unalterable by exposure to the air. According to Dr. Thomson, they contain no water of crystallization, and are composed of formic acid 32.1 +barytes 67.9=100.

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[40] Thomson's *System*, vol. ii. 481. Fourcroy, vol. vii. p. 282.

Gallate of barytes is a salt of little solubility; it is of a fawn colour, and dissolves more abundantly in water when mixed with an excess of base, than otherwise[41]. This salt may be considered to be a compound of one proportional of barytes 72.5+ one of gallic acid 60=132.5.

Hydriodate of barytes. This salt crystallizes in fine prisms similar in appearance to muriate of strontites. It is very soluble in water. By a red heat this salt is converted into iodide of barium. Gay Lussac. Thomson's *System of Chemistry*. Its composition may be considered to be barytes 72.5+ hydriodic acid 118.7=191.2.

Iodate of barytes. This salt may be formed by treating carbonate of barytes with iodic acid. It appears in a kind of farinaceous powder, and is very insoluble in water. Its constituents are, barytes 72.50+iodic acid 155.25=227.75. This has sometimes been called *oxiodate* of barytes.

Malate of barytes. This salt is somewhat similar in its properties to malate of lime. It is a super-malate, and consists of one proportional of barytes 72.5+one of malic acid 66=138.5.

Molybdate of barytes. This salt, like the other salts of barytes, is formed of one proportional of barytes 72.5+one of molybdic acid 66.5=139. Its properties are unknown.

Oxalate of barytes. This salt may be formed by adding a solution of oxalic acid to a solution of

[41] Fourcroy, vol. vii. page 248.

pure barytes. It first precipitates in the state of a white powder, but becomes dissolved by the addition of oxalic acid, which produces needle-formed crystals of super-oxalate of barytes. The oxalate of barytes is nearly insoluble in water. It is composed of one proportional of barytes 72.5 + one of oxalic acid 35.5 = 108.

Phosphate of barytes may be formed by adding a solution of phosphate of soda to one of muriate of barytes. It appears in the state of a white powder insoluble in water. It consists of barytes 72.5 + phosphoric acid 26 = 98.5.

Phosphite of barytes. Berzelius prepared this salt by pouring muriate of barytes into a solution of phosphite of ammonia. No precipitate appeared at first, but in twenty-four hours the glass was covered with a crust of phosphite of barytes[42]. When washed and dried, its composition was,

Phosphorous acid	24.31
Barytes	67.24
Water	8.45
	100.0

Seleniate of barytes. This salt has been formed by Berzelius, who states it to be a compound of

Selenic acid	100 0
Barytes	137 7

If this salt is composed, like the other barytic salts, of one proportional of barytes and one of acid, which Berzelius supposes, the above numbers give 52.6 for the equivalent of selenic acid.

[42] Thomson; Berzelius, *Annales de Chim. et Phys.* ii. 231.

Silicate of barytes. This salt is formed by the mixture of an aqueous solution of barytes with a solution of silicate of potash. The product is a silicate of barytes in white powder. The proportions of the constituent parts of this salt are not known.

Succinate of barytes. This salt was formed by Bergman, by dropping succinate of ammonia into muriate of barytes. In this process the salt partly precipitates, and is partly deposited in small crystals on the sides of the vessel. Bergman: Thomson. According to the above principle, this salt must be formed with one proportional of barytes 72.5+ one of succinic acid 46.7=119.2.

Tartrate of barytes is a salt sparingly soluble in water. It is decomposable by oxalic acid. It is a compound of one proportional of tartaric acid 62.5+one of barytes 72.5=135.0.

Tungstate of barytes is in the form of a white powder, which is insoluble in water. Its composition and properties are unknown.

Urate of barytes. This is a white powder in some respects resembling uric acid. Taking 33 for the equivalent number of uric acid, the composition of this salt will be one proportional of barytes 72.5+one of uric acid 33=105.5.

Zumate of barytes is an incrystallizable salt, having the appearance of gum. This salt, as appears by the name, is a compound of barytes and zumic acid. This peculiar acid was first procured by Braconnot from a preparation of fermented rice. It was named by Dr. Thomson zumic acid, from a

Greek word signifying *leaven*. The properties of zumate of barytes are as yet but little known.

Barytes will also combine with sulphur and phosphorus, and with some of the earths.

Sulphuret of barytes, as we have already shown at page 334, may be formed by heating to redness in a crucible a mixture of the native sulphate of barytes and charcoal, both in fine powder. The sulphuret of barytes which results is of a reddish yellow colour, and is composed of barium 65+ sulphur 15=80. When put into hot water, it decomposes the water, and two new compounds are formed, viz. hydrosulphuret of barytes, and hydroguretted sulphuret of barytes. The first appears in the form of crystals, while the hydroguret remains in solution.

Phosphuret of barytes may be prepared by passing phosphorus over heated barytes, or by exposing a mixture of barytes and phosphorus in a glass tube to a heat sufficient to produce the combination. It has the property of decomposing water, and from that decomposition phosphuretted hydrogen gas is evolved, which rises in bubbles to the surface of the water, and inflames as it comes in contact with atmospheric air.

Phosphuret of barium is composed of barium 65+phosphorus 11=76.

Such are the principal salts, &c. which have hitherto been made by means of barytes: the nature of the earth, and its uses in a separate state, remain to be spoken of hereafter.

When the peculiar properties and the decided characteristics of barytes became known, some persons suspected that it was a metallic oxide, and th usual methods were resorted to for its reduction. That it is the oxide of a metal very difficult to be reduced, was the opinion of Bergman and Lavoisier; but it was reserved for Davy to demonstrate and establish the truth of this conjecture. The detail of the ingenious experiments by which this philosopher separated the metallic substance, which is the base of barytes, may be seen in the Philosophical Transactions for 1810, page 63.

To those persons who have not the opportunity of referring to the Transactions of the Royal Society, the following concise account of barium, drawn up by Sir Humphry Davy himself, will probably be read with interest.

"To obtain *barium*," says he, "a quantity of pure barytes is made into a paste with water, and placed on a plate of platinum; a cavity is made in the paste to receive a globule of mercury; the mercury is rendered negative, the platinum positive, by means of a voltaic battery, containing about 100 double plates.

"In a short time an amalgam will be formed, consisting of mercury and barium. This amalgam must be introduced into a little tube made of glass, free from lead, which must be bent in the form of a retort, filled with the vapour of naphtha, and hermetically sealed. Heat must be applied to the end of the tube containing the amalgam, till all the

mercury has been driven off; there will remain a solid difficultly-fusible metal, which is barium.

"I first gained indications of the decomposition of barytes in the end of October 1807, and I obtained an alloy of it with iron in March 1808. The process of electrifying mercury in contact with the earth, was pointed out to me in the course of my inquiries by MM. Berzelius and Pontin of Stockholm, in May 1808; and in the beginning of June in the same year I obtained *the metal*.

"Barium, as procured by heating the amalgam, appeared of a dark gray colour, with a lustre inferior to that of cast-iron. It was considerably heavier than sulphuric acid; for though surrounded by globules of gas, it sunk immediately in that fluid. It instantly became covered with a crust of barytes when exposed to the air, and burnt with a deep red light when gently heated. When thrown into water it effervesced violently, disappeared, and the water was found to be a solution of barytes.

"Barium as yet has been obtained only in very minute quantities. I have never possessed enough of it to ascertain its general chemical and physical characters, and no experiments upon it have been published by any other person[43]."

Dr. Clarke of Cambridge, by exposing dry nitrate of barytes on charcoal to the intense heat of the condensed hydroxygen flame, observed metallic globules in the midst of the boiling fluid, and the

[43] *Elements of Chemical Philosophy*, page 338.

charcoal was found to be studded over with innumerable globules of a pure metal of the most brilliant lustre and whiteness. On letting these globules fall from the charcoal into water, hydrogen was evolved in a continued stream. Ure's *Dictionary*.

Thus have we seen that there are two minerals abundantly distributed in nature; the one called *witherite* or carbonate of barytes, the other *cawk* or sulphate of barytes; and that by various means the carbonic and sulphuric acids may be detached, and the earth, or pure barytes, obtained in a separate state. We have seen also, that the barytic earth itself is a compound body,—the oxide of a peculiar metal,—and that by means of voltaic electricity, the oxygen may be abstracted from it, and the metallic base separately obtained.

Nothing now remains but to offer a few remarks on the uses to which this singular earth may be applied.

Hitherto it has chiefly been employed as a chemical test, and in the formation of certain barytic salts already described. It has also been used by a few scientific physicians, in certain diseases, with very good effect.

In the year 1784 Dr. Crawford made his first experiments on the powers of muriate of barytes on the animal economy; and in the year 1788 many trials were made of it in desperate cases admitted

into St. Thomas's Hospital[44], and in a variety of instances these attempts proved remarkably successful. An account of the cases in which it was more particularly useful may be seen in the work quoted below.

The late Mons. Pelletier, in his observations on strontites and barytes, writes thus: "The success," says he, "which Dr. Crawford met with in the internal use of muriate of barytes, in the treatment of scrofulous diseases, begins to be known in France, and several physicians already prescribe this new medicine[45]." From hence it would seem that the medicine has been more used in France than in this country.

It has been often said, that there is a fashion in medicine; but it is a singular circumstance, that the English physicians, who were the first to employ barytes as a medicine, should nearly give up its use, when the French, who had been in the habit of giving muriate of lime for scrofulous diseases, began to use it; and that we in our turn should adopt the muriate of lime, which is now the common English medicine for such complaints, after the French had abandoned it.

Considering, however, the poisonous quality of barytes, it will surely be necessary to institute many experiments before sufficient confidence in its safety can be acquired, or before the nature of its effects

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[44] See a paper on the medicinal properties of the muriated barytes, by Dr. Adair Crawford, in vol. ii. of *the Medical Communications*, London, 1790, pages 301—360.

[45] See Nicholson's *Journal*, 4to, vol. i. page 529.

on the animal economy can be thoroughly understood and properly appreciated[46].

In preparing the medicine, the utmost care should be taken to have it perfectly pure; for some specimens of the carbonate of barytes contain copper, and others arsenic. An attention should also be paid to the saturation of the acid; for it will be very difficult to obtain an uniformity in the doses, unless a saturated solution be always employed, or the water be fully saturated, whenever the medicine is prepared by dissolving the crystallized salt: not but that a solution, however dilute, might be employed, if the exact quantity of barytes in each dose could be accurately ascertained.

Dr. Crawford has, however, remarked, that if a saturated solution be administered, a *very small* quantity of muriatic acid should be previously added to each dose, to remove the bitter taste which is peculiar to this salt, and occasion it to sit pleasantly on the stomach. But no unskilful person should ever venture to administer barytes internally, in any form.

From the appearances which pure barytes presents when slaked, and especially from its ready solubility in water, one would suppose it would be useful in making hard and tenacious cements, par-

[46] I am credibly informed that the muriate of barytes has been found to be a specific in some obstinate cases of worms, which had resisted all the common formulæ; and that a nostrum, which has been very justly celebrated for the cure of this complaint, has barytes for its base.

ticularly for important purposes. This I think was hinted by one of the French chemists; but I never heard of its having been employed in this way.

It may, however, be tried at a trifling expense (by any one who is in possession of a good reverberatory furnace) upon the sulphate of barytes. This, when ground small and mixed with one-third of its weight of pulverized charcoal, should be submitted to a red heat, as before mentioned, in order to convert the acid to sulphur. To effect this, the barytic salt, mixed as above, must be put into strong iron vessels, and well covered by charcoal to prevent the access of atmospheric air, which would not fail to re-convert the sulphur to sulphuric acid; and then submitted to the continued heat of a furnace. The sulphuret of barytes which will result is to be decomposed by any of the common means, and the remaining earth preserved for use in close vessels.

For some underground works of importance, this earth might be highly valuable and useful. As a cement for porcelain and glass, I should think it would surpass every other preparation. Nevertheless, it must be remembered, that every thing would depend upon its being applied at the moment of its being mixt with the water.

But there is a purpose not yet mentioned, to which this peculiar substance might be applied, that would be of more importance, medicine excepted, than any other for which it can be used. I allude to the decomposition of the alkaline sulphates, and the separation of their alkali.

Whenever the carbonate of this earth shall be found in as great plenty as its sulphate, we shall have within ourselves ample means of preparing the mineral alkali, and not be dependent on Spain and other places, as is the case at present.

If common salt should ever be obtained duty free, the maker of alkalies might procure it at about 40*s.* per ton; and then, if he could not get the carbonate of barytes, it might answer his purpose to employ the sulphate in its decomposition, though it would be necessary to convert the sulphate into a sulphuret, and then to separate the sulphur by some other process[47].

If the barytic earth, thus prepared, be simply thrown into a solution of sulphate of soda, it will immediately occasion its decomposition, and sulphate of barytes with caustic soda will be produced.

The abundance of pit-coal which is distributed in various places, together with our other peculiar advantages, have enabled this island, as a manufacturing country, hitherto to stand unrivalled: how much therefore is it to be regretted that two such invaluable treasures as our mines of rock salt and barytic earth should still be locked up from an enterprising people, by a prohibitory, impolitic, and excessive impost!

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[47] The opinions of those respectable chemists, Messrs. Guyton and Carny, respecting the means which ought to be adopted in preparing the native barytic salts, for the decomposition of the alkaline residuums, may be seen in the *Annales de Chimie*, tom. xix. page 109—113.

ESSAY VI.

ON

CARBON.

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ON

CARBON.

CARBON is a name now universally adopted for charcoal, or rather for that pure part of its basis which, during combustion, combines with oxygen, and escapes in the form of carbonic acid or fixed air. Carbon is so abundant in nature, that it occurs plentifully in the animal, the vegetable, and the mineral kingdoms; in combination with gas, with fluids, and with solids. It is found in the bowels of the earth, in the mines of plumbago, anthracolite, jet, glance coal, and in every kind of pit coal, of which it forms the most material part. It is also separated from the lungs of all animals in the act of respiration; and it is the basis or skeleton of all vegetables, from the small anemone of the garden to the huge oak of the forest.

Notwithstanding this abundant distribution of carbon, there is some doubt whether it has ever

occurred perfectly pure in nature. The most pure state in which it has ever yet been seen is certainly that of the *diamond*[1], which, though deemed to be the most valuable of the precious stones[2], and classed with them, is now found to be nothing more than crystallized carbon, so far as the most careful chemical analysis has yet been able to discover. The precious stones are chiefly composed of one or more of the earths and metals; the diamond, on the contrary, contains no portion of any substance belonging to either of those classes of bodies; though Sir Humphry Davy has asserted that the diamond contains a small portion of oxygen.

There is, however, a great difficulty attending this subject. Has the diamond been dissolved in water in the bowels of the earth, or could it otherwise have acquired that peculiar crystalline form in which we see it?—And yet we cannot comprehend how it could be dissolved in that fluid; for, in our hands, water has no action whatever upon it, nor

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[1] Fourcroy remarks, that "in many compounds, carbon, though very abundant, leaves them frequently a very brilliant white colour, like that of cotton, &c. The diamond is the more *white* and transparent the purer it is." *System of Chem. Knowledge*, vol. i. page 247. For some curious remarks on the *black* colour of charcoal, see Dr. Bancroft on the *Philosophy of permanent Colours*, page 48, and *Annales de Chimie*, vol. v. page 80.

[2] Diamonds are sold by the carat, a weight equivalent to four grains. Unblemished diamonds, when polished, are worth about 6*l.* per carat. The mode of calculating their value is by squaring the number of carats which the diamond weighs, and then multiplying the amount by the agreed price of a single carat. Thus it is, that those which are of an unusual size always cost

does water exert any solvent power on carbon, in any state in which we can submit it to its action.

The diamond is indeed the hardest substance in nature, and hence there is no way of grinding or polishing diamonds but by acting upon them with their own powder, which is obtained by laborious rubbing of them one against another. This method, together with the art of polishing diamonds, was brought into Europe in the year 1456. If the diamond be exposed to the sun, it refracts and decomposes the rays of light more effectually than any other transparent body[3].

Carbon has neither taste nor smell; it is a bad conductor of heat; is altogether insoluble in water, and is perfectly infusible by the strongest fire that can be applied, provided it be defended completely from the access of atmospheric or any other air containing oxygen. It has also the property of deoxidizing the oxides of metals, and other combustible substances; and of decomposing many of the sul-

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immense sums. That at the court of Russia, which weighs 779 carats, would, upon this calculation, amount to upwards of three millions six hundred and forty thousand pounds sterling. But the value of brilliants is often modified by their form, as has been very satisfactorily shown by Mr. Jeffries in his very lucid and ingenious treatise. See Jeffries *On Diamonds and Pearls*, 69 octavo pages, with 30 plates, price one guinea.

[3] On the diamonds of Brazil, see *Annales de Chimie*, xv. page 82; Mawe's *Treatise on Diamonds and Precious Stones*; or his *Travels in the Interior of Brazil*, quarto, London 1815. Mr. Smithson Tennant's memoir on the nature of the diamond will be found in the *Philosophical Transactions* for 1797, page 223.

phuric salts. In a crystallized state, it forms, as we have seen, the diamond. The representative number of carbon is 5.7.

Rouelle the younger proposed a problem in the *Journal de Médecine* for October 1762, which shows that he imagined he could dissolve vegetable coal in the palm of the hand[4]. How he could effect this I confess I have no idea, as none of the fluid menstrua with which we are acquainted have any perceptible action whatever, as solvents, upon carbon.

Strong nitrous acid, by peculiar management, may, we know, be made to inflame carbon, and when once thus inflamed it will burn with considerable brilliancy; but this arises from the decomposition of the acid, and is owing to the rapid combination of its oxygen with the charcoal, for which it has a powerful affinity.

Carbon, in certain states, combines readily with oxygen; and two distinct combinations may be formed by their union, viz. carbonic oxide and carbonic acid. Both these are gaseous products; and as the latter contains the lesser proportion of carbon, and was the first discovered, we shall speak of this in the first instance.

Carbonic acid is always produced by the burning of charcoal or other carbonaceous matter in oxygen gas or in atmospheric air. It is not necessary, however, to burn charcoal for the production of

[4] Other curious experiments by Rouelle may be seen in *Mém. de l'Acad. Roy. de Paris*, Année 1747, page 49 &c.

this gas, as it may be obtained more easily from powdered chalk, limestone, or marble, by the action of diluted sulphuric or muriatic acid, and by receiving the gas over water or mercury as it is evolved. It is also produced in every case of vinous fermentation, is given out during the decomposition of animal and vegetable substances, and is very abundantly thrown off by the action of fire in the process of lime-burning.

For the knowledge of carbonic acid we are indebted to the late Dr. Black, who discovered it in the year 1755: Mr. Keir first suspected it to have acid properties, but its composition was not known until 1772, when this was ascertained by Lavoisier, who in the same year burnt a diamond, and found the product to be carbonic acid gas. Certain individuals in the Academy del Cimento at Florence, nearly eighty years before this, had been able to burn the diamond by means of a lens, but they seem to have had no idea of the real nature of the product of the combustion. Those of my readers who shall be desirous of repeating this experiment, will be glad to be informed, that a drawing of a new and complete apparatus for this purpose may be seen in Mr. Brande's *Manual of Chemistry*, second edition, vol. i. page 425.

Carbonic acid gas has the following properties. It has no colour, and consequently is invisible. It is a heavy gas, its specific gravity being to that of hydrogen as 20.7 to 1. One hundred cubical inches, at a mean temperature and pressure, weigh 46.37

grains. It is incapable of supporting combustion; for if it be poured from a jar or other vessel into one in which a taper is burning, the flame will be immediately extinguished.

Carbonic acid is not respirable; but when combined with water, it imparts to it a pleasant acidulous taste and an agreeable smell. At a mean temperature, and under the usual pressure of the atmosphere, water is capable of taking up carbonic acid equal to its own volume, and under the pressure of two atmospheres it will take up twice its volume; but whatever may be the quantity that it has condensed, the whole of it is easily expelled by heat. Carbonic acid combines readily with the alkalies, with what are called the alkaline earths, and with several of the metallic oxides, and with them forms those salts called carbonates. It changes litmus-paper, and some other of the delicate vegetable blues, to a red; and in the proportion in which it usually occurs in the atmosphere is favourable to the growth of vegetables; though in a large proportion it is injurious.

Carbonic acid is accumulated in immense quantities in the chalk-beds and in the mountains of limestone and marble; it is also found in abundance in many natural waters, such as those of Pyrmont, Spa and Seltzer; and these are imitated in London and other parts of the kingdom by the makers of what are called single and double soda water, which are prepared by the artificial impregnation of water with carbonic acid gas. For the methods of ascer-

taining the qualities of such waters, whether natural or artificial, Kirwan's *Essay on the Analysis of Mineral Waters* may be consulted, as it is the best work we have on the subject.

Carbonic acid abounds also in some wells and caverns, where, in consequence of its great specific gravity, it often occupies the lower part of a pit, while the upper is tolerably free from it. When in these situations, it is known to miners by the name of the *choak-damp*. The presence of this gas may be ascertained by letting down a lighted candle into the suspected well, in which, if it be unsafe to enter, the candle would be immediately extinguished; or by lowering a glass of lime-water, which is rendered turbid by the choak-damp, as carbonic acid precipitates lime in the state of carbonate of lime.

If hydrogen be taken as *unity*, the equivalent number for carbon will be 5.7; and this, when united with two atoms of oxygen =15, will form carbonic acid, which will consequently be represented by 20.7. Or its composition may be stated thus:

Carbon 27.5 + oxygen 72.5 = 100 carbonic acid.

Mr. Tennant was the first person who decomposed carbonic acid, which he effected by burning phosphorus in a close vessel, in which was a portion of carbonate of soda. The phosphorus combined with the oxygen of the carbonic acid, and the carbon appeared in the state of a black powder.

Sir Humphry Davy effected its decomposition by a different means,—by its action upon potassium.

"If," says he, "this metal is strongly heated in a retort containing the gas, the potassium takes fire and burns with a red light. Charcoal in fine powder is deposited, the gas disappears, and oxygen is found added to the potassium[5]."

Carbonic oxide is the other combination of carbon and oxygen. This gaseous product may be obtained from a variety of substances containing carbonic acid, by mixing such substances in favourable circumstances with others that are capable of abstracting a portion of oxygen from the carbonic acid; as by igniting together dried chalk and the filings of iron or zinc, taking equal weights of each; or by passing carbonic acid gas over charcoal heated to whiteness, in a tube of earthenware or porcelain. The gas should be well washed with lime-water to abstract any carbonic acid that may be attached to it; it may then be preserved in jars confined by water, as water absorbs not more than $\frac{1}{50}$ of its volume of carbonic oxide. This gas was one of the latest of Dr. Priestley's discoveries; and he obtained it by the ignition of the black oxide of iron with charcoal, and by heating a similar oxide with the carbonate of barytes. We are, however, indebted to Mr. William Cruickshank of Woolwich for the true explanation of its nature and properties, in an interesting paper published by the late Mr. Nicholson in his Journal for April 1801, and in another

[5] *Elements of Chemical Philosophy*, page 302.

paper in the month of September in the same year[6]. Messrs. Clement and Desormes were, I believe, the first persons who undertook to verify Mr. Cruickshank's experiments, the result of whose examination was published in the *Annales de Chimie*[7]. Mr. Cruickshank discovered that those metallic oxides which retain their oxygen most obstinately, yield the greatest quantity of carbonic oxide[8].

Carbonic oxide may be passed through a red-hot porcelain tube without undergoing any change; it is however combustible, and when mixed with atmospheric air, burns with a lambent blue flame. It produces less heat than other inflammable gases, but may be inflamed at a much lower temperature. None of the metals exert any action upon it, except potassium and sodium, which at a red heat burn in it by abstracting its oxygen, and carbon is deposited[9]. When burnt in a dry glass receiver of oxygen gas, no moisture is deposited on the glass, which shows that it contains no hydrogen. Like most other gases, it is invisible; its specific gravity is somewhat less than that of atmospheric air; its smell is offensive; it has the property of uniting with chlorine, and with it forming a highly interesting compound, which we shall describe hereafter: it is, as has already been said, combustible; but it is a gas that will not of itself either support combustion or animal respiration. It may be taken into

[6] Nicholson's 4to *Journal*, vol. v. pages 1 and 201.
[7] *Annales de Chimie*, vol. xxxix. pages 26—64.
[8] Nicholson's *Journal*, vol. v. page 3.
[9] Brande's *Manual*, vol. i. page 421.

the lungs, but is fatal to animal life. "I once took," says Sir Humphry Davy, "three inspirations of it mixed with about a quarter of common air; the effect was a temporary loss of sensation, which was succeeded by giddiness, sickness, acute pains in different parts of the body, and extreme debility; some days elapsed before I entirely recovered[10]. Mr. Witter of Dublin was struck down in an apoplectic condition by breathing this gas; but he was speedily restored by the inhalation of oxygen. Mr. Witter himself has given an interesting account of the transaction in the *Philosophical Magazine*[11].

Carbonic oxide has a specific gravity when compared with hydrogen as 13.2 to 1; one hundred cubical inches of it weighing 29.7 grains. It contains more carbon, and yet is lighter than carbonic acid; carbonic acid being found to contain exactly twice as much oxygen as carbonic oxide. If the representative number of carbon be considered 5.7, as already stated, the composition of carbonic oxide gas will be one proportional of carbon 5.7 + one of oxygen 7.5 = 13.2 carbonic oxide.

Chlorocarbonic acid is a compound of carbonic oxide and chlorine. These two gases do not combine by mere mixture, or even by passing electric sparks through them: but by exposing a mixture of equal volumes to the intense light of the sun, they

[10] *Elements of Chemical Philosophy*, page 303.

[11] Ure's *Dictionary*, art. Carb. Ox. *Philosophical Magazine*, vol. xliii. page 367.

combine rapidly, and a condensation equal to half the original bulk takes place. The ingenious discoverer of this compound gas, Dr. John Davy, in consequence of the mode by which it is produced, named it *phosgene gas*. This acid gas has a very peculiar and remarkably pungent odour; it is the heaviest of all the known gases, 100 cubical inches of it weighing 105 grains, which is nearly four times as much as an equal volume of atmospheric air. It is decomposed by water, and the resulting gases, as might be expected, are muriatic and carbonic acid gases. The weight of chlorocarbonic acid to hydrogen is as 46.7 to 1. It is capable of saturating more of an alkali, or an alkaline earth, than any other acid. Four times its volume of ammoniacal gas is condensed by it, and a white salt is produced with a considerable evolution of caloric. Chlorocarbonic acid is a compound of one proportional of carbonic oxide 13.2+chlorine 33.5=46.7.

Carbon unites with *hydrogen*, and forms two gaseous products totally distinct from each other, the one called carburetted hydrogen gas, similar to what the miners call the fire-damp; the other supercarburetted hydrogen, or olefiant gas.

Carburetted hydrogen gas is carbon dissolved in hydrogen. In hot weather this gas is abundantly formed at the bottom of pools of stagnant water, and may be collected by means of a common pneumatic apparatus at its surface. It is procured in the large way by the dry distillation of pit-coal, and

is the gas which is now employed for lighting the public streets, manufactories, &c. One pound of coal yields about 24 gallons of this gas, and as this always contains a portion of sulphuretted hydrogen and carbonic acid gas, it is usual to pass it through a mixture of lime and water, that these gases may be absorbed, and the carburetted hydrogen rendered sufficiently pure to pass into the gasometers for use.

As Professor Brande has been engaged in a laborious series of experiments on this gas[12], I conceive that I cannot do better than avail myself of his experience for the information of my readers.

"The specific gravity of the gases obtained from stagnant ponds is liable to great variation, 100 cubical inches weighing from 12 to 20 grains. They burn with a paler flame, and require less oxygen than *olefiant gas*[13] for perfect combustion.

"The average specific gravity of purified coal gas is 0.4500: 100 cubical inches weigh from 14 to 15 grains, and it may be considered as a mixture of about 55 volumes of hydrogen and 45 of olefiant gas.

"The best kind of coal for distillation is that which contains most bitumen and least sulphur. The chaldron should yield about 12,000 cubical feet of purified gas, of which each Argand burner, equal to six wax candles, may be considered as consuming from four to five cubical feet per hour.

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[12] *Philosophical Transactions* for 1820.

[13] The nature of olefiant gas will be explained in the next article.

"The economy of gas illumination may be judged of by examining the value of the products of the distillation of a chaldron of coals, the average cost of which may be considered as 3*l*. It should afford

	£.	s.	d.
1¼ chaldron of coke, at 25*s*. per chaldron ..	1	11	3
24 gallons of tar and ammoniacal liquor, at 3*d*.	0	6	0
12,000 cubic feet of gas, at 15*s*. per 1000 feet ..	9	0	0
	£10	17	3

"These products are taken at their lowest value; but they afford ample grounds for showing the advantage of gas illumination, not merely for public purposes, but also in private establishments. It appears that where more than fifty lights are required, a coal gas apparatus will be found profitable."

It is however generally allowed, that the gas which is procured from oil affords more light according to its volume than coal gas; and it has been estimated that from two to three cubic feet may be regarded as equivalent to five or six of coal gas in this respect.

"The commonest whale oil," says Mr. Brande, "or even pilchard dregs quite unfit for burning in the usual way, afford abundance of excellent gas, requiring no other purification than passing through a refrigerator, to free it of a quantity of empyreumatic vapour.

"A gallon of whale oil affords about 100 cubical feet of gas, and an Argand burner equal to seven candles consumes a cubical foot and a half per hour. The cost of a lamp fed *by oil or coal gas*,

and giving the light of seven candles, will be three farthings per hour. The cost of

An Argand lamp with spermaceti oil	3*d.*	per hour.
Mould candles	3½	do.
Wax candles	14	do.

"By a series of experiments, conducted with caution, I found that, to produce the light of ten wax candles for one hour, there were required,

2600	cubical *inches*	of olefiant gas.
4875	do.	of oil gas.
13,120	do.	of coal gas.

"Experiments thus conducted show that purified *coal gas* seldom contains more than 40 per cent. in volume of carburetted hydrogen, while *oil gas* generally affords about 75 per cent.; hence its superiority for burning, and the relatively small quantity consumed[14]."

M. Berthollet instituted a series of experiments on the decomposition of oil for the production of gas, which may be considered important from the results which he obtained. The product which is usually afforded, is *a mixture* of gases; but this experimental philosopher, by a judicious regulation of the temperature, prevented the other gases from rising, and obtained olefiant gas in a state of purity[15].

Messrs. J. and P. Taylor, of Bury Court, St. Mary Axe, and Mr. James De Ville of the Strand, London, are the persons who are principally en-

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[14] Brande's *Manual*, vol. i. pages 438—442. *Journal of Science*, vol. i. pages 71—80.

[15] *Mémoires de la Soc. d'Arcueil*, tom. ii. 84. and tom. iii. 154.

gaged in this country in constructing the apparatus for the conversion of oil into gas.

An ingenious and highly estimable friend of mine, who has lately been engaged in lighting some of the principal streets of Paris with oil gas, does it in a way never before attempted. He thus writes: "We are going on quite a new principle. Coal is very dear and bad here, and it struck me that the oleaginous seeds, which are cheap and abundant, might answer the purpose. We made our experiments, and found that by this means we can produce a cheaper and better gas than from coal, and more so than from oil. For by taking the oil seeds we save all the waste and expense of extracting the oil, and have the substance in a much fitter state for decomposition. We have a patent for this invention in France, and have met with great encouragement from the Government." How delightful is it to observe that the constituted authorities in every country of Europe are lending their assistance in the prosecution of schemes of improvement, and in aiding the efforts of individuals for increasing the comfort, and promoting the civilization of the general community!

I had hitherto forgotten to observe that Dr. Henry has devoted a considerable time to the investigation of the nature of the gas from mineral coal; and this is the more inexcusable, as he was the first experimental philosopher who avowed that he did not consider this to be a subject beneath his notice.

So early as the year 1805 Dr. Henry instituted

a series of "experiments on the gases obtained from wood, peat, pit-coal, oil, wax, &c. with a view to the theory of their combustion, when employed as sources of artificial light," and the result of his experiments was published in Nicholson's *Journal*[16]. This memoir contains a table of results, and a variety of very interesting observations. Three years afterwards this ingenious philosopher resumed his experiments, an account of which may be seen in the *Philosophical Transactions*[17]; and in the latter end of the year 1818 and the beginning of the following year, in consequence of an application from the proprietors of some large manufactories lighted by gas in the neighbourhood of Manchester, he once more returned to the investigation of the subject. The paper giving an account of these latter experiments was read to the Literary and Philosophical Society of Manchester on the 19th March 1819, and afterwards published in their Memoirs[18]. It consists of distinct chapters on the following subjects, viz. on the gases of known composition, the mixtures of which, in various proportions, according to his view, compose all the varieties; on the quality of the gas at different stages of the distillation; on the purification of coal gas; on the method of analysis; and on the chemical nature of the gas from coal; together with several tabular represen-

[16] Nicholson's *Journal*, Oct. vol. xi. pages 65—75.

[17] *Philosophical Transactions*, 1808, page 282, &c.

[18] *Memoirs of the Literary and Philosophical Society of Manchester*, Second Series, vol. iii. pages 391—429.

tations, all which deserve the attention of those persons who are desirous of becoming thoroughly acquainted with this subject.

Before the middle of the last century, the Rev. Dr. John Clayton ascertained by experiment, that mineral coal evolves a permanently elastic fluid, fit for the purposes of affording light and heat; and he communicated the discovery in a letter to the Hon. Robert Boyle. This letter was read before the Royal Society in January 1739, and in the year 1741 was printed in the Society's *Transactions*[19]. The discoverer calls the gas the *spirit of coals*. The circumstances which he relates as having led to the discovery, are highly interesting; but on reading the Doctor's account of the results which he obtained, it seems very extraordinary that neither he nor any of the fellows of the Royal Society, nor others to whom the experiment was shown, should have thought of turning it to an economical account.

For the first application of carburetted hydrogen gas to the purpose of illumination, the public is certainly indebted to Mr. W. Murdoch, the particulars of which Dr. Henry first published in the year 1805 as a postscript to an account of his own experiments[20]. From this communication I can only make a few brief extracts, and must refer to the paper itself for the remainder.

In the year 1792, at which time Mr. Murdoch

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[19] *Philosophical Transactions*, vol. xli. page 59.
[20] Nicholson's *Journal*, vol. xi. page 73.

resided at Redruth in Cornwall, as principal agent for Messrs. Boulton and Watt in that county, he commenced a series of experiments upon the quantity and quality of the gases contained in different substances. In the course of these, he remarked that the gas obtained from coal burnt with great brilliancy upon being set fire to; and it occurred to him, that by confining and conducting it through tubes, it might be employed as an economical substitute for lamps and candles.

At this time Mr. Murdoch was too much engaged to attend further to the subject; but in 1797 he repeated the experiments in presence of numerous spectators at Old Cumnock in Ayrshire, and in 1798 he actually constructed an apparatus at Soho foundery, which was applied during many successive nights to the lighting of the building. These experiments were occasionally continued until the spring of the year 1802, when upon the occasion of the public rejoicings for the peace, the illumination of the whole of the Soho manufactory afforded an opportunity of making a display of the new lights; and they were made to constitute a principal feature in that exhibition.

Three years after this public display at Birmingham Messrs. Phillips and Lee of Manchester lighted up their extensive establishment in that town with coal gas issuing from nearly a thousand burners. This grand application of the new principle satisfied the public mind, not only of the practicability, but also of the economy of the application; and as

a mark of the high opinion they entertained of his genius and perseverance, and in order to put the question respecting the priority of the discovery beyond all doubt, the Council of the Royal Society awarded to Mr. Murdoch the gold and the silver medal founded by the late Count Rumford.

Nothing but the importance[21] of the application of the gases from oil and coal could have justified me in going so far into detail, especially if I had had to explain the nature of the carburetted gas which perpetually occurs in the coal districts, and which it would have been incumbent upon me to have treated of in this essay, if I had not anticipated the subject in a former part of this volume[22]. I proceed now to consider the nature of the other gaseous compounds of carbon.

Super-carburetted hydrogen is a compound of carbon and hydrogen, in which the hydrogen combines with exactly twice as much carbon as it does in the carburetted hydrogen gas already described. It is highly inflammable, and emits more light during its combustion than is given out by the inflammation of the former. This super-carburetted gas is now generally known by the name of *olefiant* gas; and under that name has been already referred to in the former parts of this essay.

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[21] The manufacture of coal gas is important in another view, as the waste liquor now furnishes most of the subcarbonate of ammonia, the common smelling salts of the shops, and is also employed with great advantage as a manure for land.

[22] See the *Essay on Temperature*, pages 127—140.

Olefiant gas is generally evolved during the destructive distillation of oil, pit-coal, and other substances; but for the purpose of experiment it is usually procured by heating a mixture of four parts of sulphuric acid and one of alcohol in a retort, and collecting the gas over water as it is generated. When kindled, it burns with a beautiful white flame of great splendour. One volume of this gas, in consequence of the condensation of its hydrogen, requires three volumes of oxygen for its combustion, during which two volumes of carbonic acid are produced. Heat alone will decompose it; for if one volume of this gas be frequently passed through a red-hot tube, the hydrogen will deposit its charcoal, and become expanded to two volumes, its natural bulk.

The decomposition of olefiant gas, by heating it in conjunction with oxygen, affords a beautiful exemplification of the atomic system, thus:

1 atom of carbon 5.7 + 1 atom of hydrogen 1 = 6.7 olefiant gas.

If this be mixed with

3 atoms of oxygen 7.5 × 3 = 22.5

29.2

the mixture on detonation will produce as under:

The 1 atom of hydrogen 1 + 7.5 oxygen = 8.5 water
The 1 atom of carbon 5.7 + 15.0 oxygen = 20.7 carbonic acid.

29.2

Carburetted hydrogen is compounded of one atom of carbon and two of hydrogen; whereas ole-

fiant gas is a compound of one atom of carbon and one of hydrogen; and may be represented thus :— One atom of carbon 5.7+ one atom of hydrogen 1, will give the representative number of 6.7 for supercarburetted hydrogen or olefiant gas.

Chloric ether may be formed by allowing a current of chlorine and one of olefiant gas to meet in a proper receiver. There should be excess of olefiant gas; for if the chlorine be in excess, the liquid absorbs it. It is transparent and colourless; its taste sweet and somewhat acrid; its specific gravity 1.2. It boils at 152°. It burns with a green flame, evolving muriatic acid, and largely depositing charcoal. As it is produced by equal volumes of chlorine and olefiant gas, it is probably a compound of one proportional of chlorine 33.5+ two of olefiant gas 6.7× 2=13.4=46.9 chloric ether[23].

Perchloride of carbon. Mr. Faraday has ascertained that, by exposing olefiant gas, mixed with great excess of chlorine, to the action of light, a white crystalline substance is formed, which, when purified by washing with water, is a perchloride of carbon. This substance is nearly tasteless; its odour resembles camphor; its specific gravity is about 2; it is a non-conductor of electricity. It is volatile; and in close vessels fuses at 320°, and boils at 360°. It is not very combustible, but burns

[23] Brande, vol. i. page 437.

when held in the flame of a spirit lamp, with the emission of much smoke and acid fumes. It is insoluble in water, but readily soluble in alcohol and ether, and the solutions deposit arborescent and quadrangular crystals. It also dissolves both in volatile and in fixed oils. It is scarcely acted upon by alkaline and acid solutions; but most of the metals decompose this substance at a red heat. Potassium burns brilliantly in its vapour, causing the deposition of carbon, and the production of chloride of potassium. It appears from various analytical experiments upon this compound, that 100 parts afford 10 carbon and 90 chlorine; whence it would appear to consist of

2 proportionals of carbon .	$5.7 \times 2 = 11.4$
3 do. of chlorine . . .	$33.5 \times 3 = 100.5$
	111.9

Protochloride of carbon. When the perchloride of carbon is passed through a red-hot tube, containing fragments of rock crystal to increase the heated surface, it gives off a portion of chlorine, and is converted into a liquid protochloride of carbon. It is a limpid colourless fluid; specific gravity 1.55, and not combustible, except retained in the flame of the spirit lamp, when it burns with a yellow flame, much smoke, and fumes of muriatic acid. It does not congeal at 0°; it rises in vapour at about 165°. It is insoluble in water, but soluble in alcohol, ether, and the oils. It is not affected by the acids or alkalies, nor, at common temperatures, by

solutions of silver. It dissolves chlorine, iodine, sulphur and phosphorus[24]. This extraordinary substance affords, when decomposed, 17 parts carbon and 83 chlorine; whence it may be inferred to consist of

1 proportional of carbon	5.7
1 do. of chlorine	33.5
	39.2

Hydriodide of carbon. When iodine and carburetted hydrogen are exposed to the action of light, they combine and form a hydriodide of carbon. This compound was first obtained, in the laboratory of the Royal Institution, by Mr. Faraday. The hydriodide of carbon is a white crystalline solid, volatile without decomposition, and in many respects analogous to the hydrochloride of carbon, or chloric ether above described. Its taste is sweet, and its odour aromatic[25].

Carburet of nitrogen. This gas was discovered by Gay Lussac, and announced in one of the volumes of the *Annales de Chimie* for 1815[26], under the name of *cyanogen*. It is here generally called prussic gas. It may be obtained by decomposing the cyanuret, or prussiate of mercury, by heat. It has a very powerful smell, somewhat like that of bitter almonds, and affects the nostrils violently when inhaled by them. It is a permanently elastic fluid, very inflammable, and nearly twice as heavy

[24] Brande, vol. i. pages 433 & 434. [25] *Id. ibid.* 438.
[26] See *Annales de Chimie*, xcv. page 136—231.

as atmospheric air; its specific gravity, compared with hydrogen, being 24.4. One hundred cubic inches of it weigh 54.9 grains. Water dissolves 4.5 volumes, and alcohol 23 volumes of this gas. The aqueous solution is sharp and penetrating to the taste, and highly poisonous. The gas burns with a beautiful purple flame inclining more to blue than red. Carburet of nitrogen, or prussic gas, consists of two proportionals of carbon 11.4+one of nitrogen 13=24.4, which may be considered to be the representative number of this gaseous compound.

Chlorocyanic acid. This compound of the prussic and chlorine gases was first formed by the illustrious M. Gay Lussac, and described by him in the paper already alluded to in the 95th volume of the *Annales de Chimie.* He obtained it by passing a stream of chlorine gas into a solution of hydrocyanic or prussic acid in water; and purified it from the excess of chlorine in a way he there describes. It is void of colour and very volatile. It has a pungent and very peculiar odour; and reddens litmus like other acids. M. Gay Lussac gave it the name of chlorocyanic acid. It is composed of one atom of cyanogen 24.4+one of chlorine 33.5=57.9 chlorocyanic acid.

Hydrocyanic or *prussic acid.* This is a triple compound of carbon, nitrogen and hydrogen; or hydrogen united with prussic gas. It is usually obtained by distilling at a very low heat moistened

prussiate of mercury with muriatic acid. The acid thus obtained is a colourless liquid, has a strong smell resembling peach blossoms, its taste is very acrid and highly poisonous. At first it gives an impression of sweetness and coolness to the tongue, it then tastes hot and virulent, and sometimes excites sickness and fainting, and often violent coughing. It is a volatile acid, and when exposed the gas volatilizes so rapidly as to freeze itself. This may be shown by taking a drop of it on the end of a tube. It reddens litmus paper, but the red disappears as the acid evaporates[27]. This acid contains more nitrogen than the other animal acids, but is destitute of oxygen. It is sometimes employed in medicine, but it is preserved with difficulty, as it is the most easily decomposed of all the acids. Some observations by Sir Humphry Davy on the prussic gas and prussic acid, will be found in two distinct papers in the 1st volume of the Scientific Journal[28]. We have seen that cyanogen or prussic gas is a compound of carbon 11.4+nitrogen 13; the prussic acid is a similar compound, with the addition of one proportional of hydrogen 1, which makes the representative number 25.4.

Cyanogen and Iodine. This compound has been formed by Sir Humphry Davy, by heating iodine with prussiate of mercury. "The compound," says he, "is a very curious body; it is volatile at a

[27] Mr. Porret *Philos. Trans.* for 1814. M. Gay Lussac *Annales de Chimie*, tome xcv. pages 136 &c.

[28] *Journal of Science and the Arts*, vol. i. pages 283 & 288.

moderate heat, and on cooling collects in flocculi, adhering together like oxide of zinc formed by combustion, and it has a very acrid taste and pungent smell." In this paper Sir Humphry Davy intimates a wish that M. Gay Lussac could be prevailed upon to give up the inexpressive and difficult names of *cyanogen* and *hydrocyanic acid*, and to adopt the simple ones of *prussic gas* and *prussic acid*[29].

Sulphuret of carbon. This is a colourless liquid of the specific gravity of 1.272[30], highly inflammable, and capable of forming compounds with the earths and alkalies. It boils at 106°, though it has so considerable a specific gravity, and does not freeze when cooled down to —60°. Its taste is pungent, and its odour very fetid. It was discovered by Lampadius, who from its extreme volatility gave it the name of *alcohol of sulphur*. It is obtained by passing the fumes of sulphur over red-hot charcoal. Dr. Marcet has discovered that sulphuret of carbon has the property of producing cold far exceeding that of any other known substance. In the receiver of an air pump mercury may be readily frozen by its means. Iodine dissolves in sulphuret of carbon, and changes it to a dark reddish brown colour. One grain of iodine will impart a deep colour to 1000 grains of the liquid. Sulphuret of carbon is a compound of one proportional of carbon 5.7 + two of sulphur 30 = 35.7. Messrs. Clement and Des-

[29] *Journal of Science and the Arts*, vol. i. page 289.
[30] *Philosophical Transactions*, 1813, page 175.

ormes, in a paper on carbon; M. Berzelius; and Professor Brande, have written on this curious compound fluid[31].

Phosphuret of carbon. The formation of this substance was first noticed by Proust, who described it under the above name in the *Annales de Chimie*. There is some difficulty in obtaining it as he directs; but Dr. Thomson says he never failed to procure it by the following method: "Allow phosphuret of lime to remain in water till it has given out all its phosphuretted hydrogen gas; then add to the liquid a considerable excess of muriatic acid; agitate for a few moments, and throw the whole upon a filter. Phosphuret of carbon will be found upon the filter, which is to be washed and dried.

"Phosphuret of carbon thus obtained, is a soft powder of a dirty lemon yellow colour, without either taste or smell. When left in the open air, it very slowly imbibes moisture, emits the smell of carburetted hydrogen, and acquires an acid taste. When the powder is thrown over the fire in small quantities at a time, it burns in beautiful flashes." It is composed, according to Dr. Thomson, of one atom phosphorus, and one atom carbon; or by weight, phosphorus 1.5, carbon 0.75.

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[31] Lampadius in Crell's *Annals*, 1796, ii. Clement, *Annales de Chimie*, tome xlii. p. 121—152. Berzelius and Marcet, *Philosophical Transactions*, 1813. Brande, *Phil. Trans.* 1820, page 19.

Taking the representative number for carbon to be 5.7, as I have done throughout, the powder must be composed of

1 proportional of phosphorus	11.0
1 do. of carbon	5.7
	16.7

In treating of carbon it is usual to adduce charcoal as a familiar instance of its existence, carbon being the basis of all charcoal. On this account it may be proper to speak of the methods used for obtaining this article, and also of its peculiar properties.

Charcoal is too well known to require any minute description; but as every one may not be aware of its characteristic properties, it will be necessary to speak more circumstantially respecting them than I have hitherto under the word Carbon.

The charcoal of wood is light and porous, so much so that it is possible to blow entirely through it. It is also very brittle, and easily reduced to a fine powder; it absorbs light very abundantly, which occasions its blackness; at a red heat it decomposes water and reduces metallic oxides[32]; it absorbs all the gases in abundance; it decomposes many of the acids by abstracting their oxygen; it is a powerful antiseptic; is unalterable and indestructible

[32] Charcoal is so efficacious in reducing metallic oxides, that Mrs. Fulhame had no difficulty in producing the same effect, when she merely digested an alcoholic solution of potash on charcoal powder, and employed the liquor which resulted from it. Fulhame's *Essay on Combustion*, 8vo. 1794, page 126—134.

by age; is a non-conductor of electricity as well as a bad conductor of heat; it has a great affinity for oxygen when ignited; it is a useful agent in purifying rancid oils, and in abstracting the colour from syrups and saline solutions; it is one of the principal articles employed in the preparation of Mr. Hatchett's artificial tannin; and it is one of the bases of the prussic acid and of a great many other compounds.

One of the most important of these combinations is the article of gunpowder, which is generally made to contain about fifteen per cent. of charcoal. The usual proportions of its ingredients are 76 parts of well purified nitre, 9 of sulphur, and 15 of charcoal.

The first intimation that was given of gunpowder, was by that great philosopher Roger Bacon, in his posthumous treatise entitled, *De Nullitate Magiæ*, published at Oxford in 1316, nearly 150 years before the invention of printing, and about 22 years after the death of its venerable author. "You may," says he, "raise thunder and lightning at pleasure, by only taking sulphur, nitre, and charcoal, which singly have no effect, but mixed together, and confined in a close place, cause a noise and explosion greater than that of a clap of thunder."

It is observable that he only mentions the sulphur and nitre in direct terms; and, as though he were fearful of imparting the dread secret, conceals the charcoal under an anagram. The words are, "sed tamen salis petræ *lure mope can ubre*, et sulphuris, et sic facies tonitrum, et corruscationem, si scias,

artificium." The words which are printed in italics form an anagram of CARBONUM PULVERE, charcoal powder.

Polydore Vergil relates, that gunpowder was invented by Bartholdus Schwartz, a German chemist, who happening to triturate some sulphur, nitre, and charcoal in a mortar, was surprised and alarmed at an unexpected explosion, which blew off the head of his mortar to a considerable distance.

The probability is, that this was a *second* discovery of the same thing, and that he knew nothing of the disclosure which Bacon had made, and who was doubtless in possession of the secret 100 years before the time alluded to by this author.

It appears, however, that in the year 1380 Bartholdus Schwartz did actually instruct the Venetians in the use of gunpowder, and that all Italy complained of it, as a manifest innovation on the rules of warfare; although it is evident that this was not the first instance of the use of gunpowder in war; for it is related by Peter Mexia, that "when the Moors, in 1343, were besieged by Alphonsus XI. king of Castile, he discharged a sort of iron mortars upon them, which made a noise like thunder."

Similar effects, and even in a much higher degree, may be produced by the mixture of carbon with chlorate of potash, formerly called hyper-oxymuriate of potash, and sulphur; and for some purposes this terrible compound is preferable to common gunpowder. Its explosive effects are truly astonishing. Some particulars respecting this new kind of gun-

powder may be seen in the Additional Notes, No. LVI. of the Chemical Catechism.

"Pent in dark chambers of cylindric brass
Slumbers in grim repose the sooty mass;
Lit by the brilliant spark, from grain to grain
Runs the quick fire along the kindling train;
On the pain'd ear-drum bursts the sudden crash,
Starts the red flame, and death pursues the flash.
Fear's feeble hand directs the fiery darts,
And strength and courage yield to chemic arts."

Charcoal, when made on a large scale, is generally prepared in the following manner:—A large quantity of billet-wood is piled in a heap; this is covered with turfs and sand to prevent the access of atmospheric air as much as possible, and then the heap is set fire to at several holes near the bottom, which are always made for that purpose. At first a hole is left open at the top to occasion a draught, and produce a better and more regular combustion. After a time this orifice is covered with turf; and when it is perceived that the flame has pervaded every part of the heap, the holes at the bottom are closely stopped also. By this management the whole of the wood becomes ignited, though it is not burnt to ashes as it would be were a free circulation of air to be permitted; but, by closing the openings and leaving the fire smothered up, a heat is preserved sufficient to decompose and dissipate every thing of a fluid or gaseous nature in the wood, so as to leave the whole pile in a carbonized state. The mass is then allowed to cool sufficiently to be uncovered,

and the billets, now converted into charcoal, to be removed.

This method of making charcoal is doubtless very ancient. Theophrastus Eresius, the pupil and successor of Aristotle, who lived more than 300 years before Christ, has described it very fully. This excellent philosopher, who wrote more than 200 different treatises, chiefly on subjects of natural history, lamented, at the age of eighty five, "that he was to die, just when he began to know how to live."

Pliny informs us that in his days the wood was formed into a pyramid, the apex of which was covered with clay[33]. There is, indeed, abundance of evidence that the ancients were acquainted with several of the properties of charcoal, and employed it for various purposes.

It has, however, been discovered within a few years, that charcoal can be much more perfectly prepared by a method different from that which has just been described, and which is now generally adopted for the preparation of that which is consumed in the manufacture of gunpowder.

In this process the wood, previously freed from the bark, is placed within large cast-iron cylinders, which are fixed horizontally in brick-work so as to be easily heated red-hot by fires placed beneath them.

These cylinders during the distillation have no communication with the external air, but at one opening, and this is destined to allow of the escape

[33] Holland's *Pliny*, folio, London, 1601, book xvi. page 459.

of the acid and the different gases; so that, when the operation is over, nothing remains in the cylinders but the charred wood divested of all impurities.

In some manufactories the charcoal is drawn from the cylinders, while red-hot, into immensely large canisters, made with riveted plates of sheet-iron, and with moveable covers, which fit perfectly, so as to close them completely. In these it remains safely preserved from the action of the atmosphere till it is entirely cold. These canisters are so contrived, as to their number and size, as to contain the whole produce of one charge. I should be culpable, however, were I not to caution my readers against adopting this mode of conducting the business; for the circumstance of removing the charcoal from the cylinders while red-hot must very much injure the health of the workmen so employed.

In some other manufactories the wood is not put into the cylinders which are fixed in the brick-work, but into others which are made of sheet-iron, and contrived so as to fit within the former. Here the cast-iron cylinders acquire a red heat, as in the former case, and that heat is found to be sufficient to char the wood contained in the wrought-iron vessels.

When the operation is finished and the wood is found to be sufficiently charred, which is always known by the volatile parts having ceased to distil over, a block and tackle are affixed to the inner cylinders, which are drawn out in a moment, and others of the same dimensions, previously filled with billets of wood, are by the same means directly

swung into their places. In this way the process goes on without interruption, and the proprietor is enabled to allow the charcoal to cool completely, before it is removed from the vessel in which it is prepared. In order to adhere strictly to this rule, it is of course requisite to have a number of the wrought-iron moveable cylinders proportionate to the extent of the work; so that while some are cooling, others may be recharged with wood, and exposed in the fixed cast-iron apparatus to the action of the fire, and thus no time will be fruitlessly expended. Drawings of the apparatus will be found in the plates, figures 13 and 14.

It is remarkable that, although the charcoal prepared by this process is so superior for making gunpowder, it is not well calculated for some other processes. It is not of half the specific gravity of the charcoal which is made out of doors in the common way, and merely covered up with turf. The makers of iron particularly will not buy it.

This method of working does however produce better charcoal for gunpowder, and it has the advantage of furnishing a large supply of an impure kind of vinegar, or acetic acid, which is very useful in several of our manufactories. This acid was formerly considered to be of a peculiar nature, and distinct from all others; it was named the *pyroligneous* acid, and in commerce it is still known by that appellation.

When this acid is suffered to stand a few weeks undisturbed, it deposits a peculiar kind of tar, and

this in considerable quantity. Every kind of wood will produce this acid and tar, when treated by what is called the destructive distillation. Peat also will yield it in abundance. A friend of mine distilled some which was dug in Wholmer Forest, and procured pyroligneous acid from it. When this acid was redistilled, it left a residuum of tar, similar to that which is produced from the second distillation of wood acid. For some years past this tar has been a great burden on the hands of those who have been largely concerned in making the pyroligneous acid. For, though it has been employed in a great variety of ways, the consumption has never kept pace with the quantity produced, and within my own knowledge many tons of it have been buried in the earth, merely to get rid of it.

It was tried in one of the public dock-yards; but the quantity produced at that time in Great Britain was, in comparison with the quantity of pitch and tar required for the royal navy, too insignificant to permit the idea to be ever entertained of its being generally used in the Government dock-yards; particularly as it will not combine with the imported pitch and tar in common use.

I have myself, in various ways, made experiments upon this tar; and, notwithstanding this inconvenience, I am so convinced of its value, that I am desirous of making it an object of public attention.

For every kind of wood fence, it is the best preservative of any thing that can be applied. It should be gently heated in an iron pot, and put on with a

brush. When first put on, it gets so completely into the wood, that it might be supposed that it could be of little use. It soaks in, and seems to leave no *body*, as the artists express it: but if the work thus treated be examined after it has been exposed for some days to the sun, the surface and the texture of the wood will evidently be much altered; for it will now be found so impervious and hard, that it will be very difficult to make any impression upon it.

If a second, and especially if a third coat of this tar be put upon wood, it will then bear out, as the painters call it, sufficiently well; and I have reason to believe that it will preserve all outside wood-work much more effectually than it can be preserved by any other expedient that has hitherto been contrived for this very important purpose.

For ornamental paling, and indeed for all good outside work, a first, or perhaps a first and second, coat of this tar might be used with great advantage; and when these shall be completely dry, the work might be finished with white lead and oil, as usual.

Besides the extreme hardness which this article imparts to wood, it has also the advantage of effectually preserving it from worms and from all other insects. Even where wood has become worm-eaten, I have observed that this tar will stop the progress of the decay; and I am inclined to think, from what I have seen, that a paling of worm-eaten deal, if it be not absolutely rotten, will last longer when covered with this article, than a similar fence made

with new deal without such treatment. It may however be necessary to remark, that the article here spoken of is very different from the tar which is distilled from mineral coal, and that was recommended by the Earl of Dundonald, thirty years ago, for a similar purpose.

To those persons to whom a little additional expense would be no object of consideration, the following preparations are recommended. They will be found to improve the appearance of the wood to which it is applied very considerably:

1 Gallon of the tar,
1 Oz. tallow,
2 Oz. pulverized rosin, melted together and put on warm; or

1 Gallon of the tar and
2 Oz. of pulverized sulphate of iron to be used in the same manner as the foregoing mixture.

The first of these prescriptions looks the best, but the latter has been proved, and has lasted good for twenty years. How much longer it will be an effectual preservative for the wood, time only can discover.

I have occasionally made many other trials of the tar from pyroligneous acid, and I find it useful not only for wood, but also as a varnish for a variety of goods made of rolled iron, or of cast iron. A more beautiful varnish for these purposes may however be prepared by the following process: Take

1 Gallon of the wood tar, and
½ Pint of rectified spirits of wine, and let these be intimately mixed by a gentle heat.

If this composition be laid on hot and properly hardened by the air, it will prove a beautiful and durable black varnish.

As the peculiar properties of such a refuse article are not likely to be generally known, I think it a duty I owe to my country to give as much publicity to these facts as possible, by withholding no information respecting them which it is in my power to impart; particularly as the engagement which I entered into, some years ago, to take all the pyroligneous acid which should be produced at the King's cylinder works at Farnhurst in Sussex, amounting to many thousand gallons annually, gave me an opportunity of making many and reiterated experiments on this singular and important residuum.

Some time ago a very remarkable circumstance respecting the collection of pyroligneous acid from the charcoal-cylinders, came to my knowledge, which I think worth recording, as it may preserve some individuals from great loss and disappointment, and must be of considerable importance to us as a nation.

A gentleman of opulence, residing near the metropolis, who was the proprietor of some large gunpowder works, and who prepared his own charcoal for that manufactory, sustained a considerable pecuniary loss from the following occurrence.

He had for some time been collecting a portion of the pyroligneous acid, which arises from the wood in the act of charring; when a certain chemical ad-

venturer persuaded him to make an alteration in the apparatus, with the view of procuring, as it was pretended, more than double the quantity of acid.

According to this advice, he put up at a considerable expense an entirely new apparatus, which was so constructed that the pipes which conveyed the acid, as it arose from the ignited wood, passed through a large body of water, which so completely cooled it, that the whole of it was condensed and collected in the recipient. In the last pipe, exactly at the place where it emerged from the water, there was a small hole, to prevent any part of the apparatus from bursting. Whenever the cylinders had done working, it was directed that this hole should be firmly stopped, and that then the whole apparatus should be suffered to cool.

By this arrangement a much larger quantity of acid was preserved, as the adviser had predicted, and which promised an ample repayment of the expense of the alteration: but it was quickly perceived that the gunpowder was very much deteriorated; and this happening at a time when the house had a contract with Government (in which case the gunpowder is always accurately proved) several parcels were complained of, and one large delivery was actually returned as unfit for the public service.

These complaints were not only unexpected, but peculiarly mortifying, because the manufacturer had been pleasing himself with the idea that the gunpowder would be improved, and he could not

at all account for the cause of this unfortunate change in the quality of his article.

At first he suspected that the nitre might contain some deliquescent salts; but even when he had made his gunpowder from the nitre which had been refined at His Majesty's private works, where the utmost care is taken in the process, the powder was still the same. Then the sulphur was examined; and when nothing amiss could be discovered there, he began, for the first time, to suspect that the fault must be in the charcoal, although that which they were then using was in appearance finer and handsomer than any they had ever had.

The proprietor was now, however, convinced that the alteration in the quality of the powder could not possibly be otherwise accounted for than by attributing it to this alteration in his apparatus: he therefore instantly ordered the whole to be removed, and reverted to his old plan of distillation, by which one third, at least, of the acid is dissipated in gas, and entirely lost. But the consequence was evidently favourable, and the error fully detected. The gunpowder manufactured since is as good as it had formerly been, and he has received no more complaints.

This circumstance was not mentioned to me until after the new apparatus was destroyed, or I certainly would have advised the proprietor to continue the new arrangement, and to make no other alteration than merely to provide the means for the incondensable gaseous products to be properly dissi-

pated. For, by stopping up the vent-hole, the latter portions of the incondensable gas could not get away; and every chemist knows the property which charcoal has of absorbing with avidity all the gases, and in considerable quantity. If, instead of stopping up the vent-hole, several others had been opened during the last stage of the process, and suffered to remain so while the cylinders were cooling, I doubt not but this charcoal would have turned out equal in goodness to the former.

The kinds of wood which are preferred for making this kind of charcoal, are the dog-wood, the alder, and the willow[34]; and since these woods have been made use of, and the last-mentioned process has been employed for making the charcoal, any given quantity of the British gunpowder will drive a ball one third further than the powder prepared with ordinary charcoal.

This may in some measure be owing to the charcoal of these woods taking fire more quickly; for we know how much sooner the coal of some linen, when used as tinder, will take fire, than that of others, and how readily that kind of fungus burns which is called German tinder[35], a species of agari-

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[34] Within these twenty years very large plantations of dog-wood and alder have been made in the counties of Kent, Sussex, and Surry, so that at this time His Majesty's and other private manufactories of gunpowder are entirely supplied with charcoal from wood of the above descriptions.

[35] To render this fungus still more combustible, the Germans purify it from all extraneous matter by boiling it in an alkaline lye. They then dry it, and boil it again in a solution of salt-

cus, known to botanists by the name of *Boletus igniarius*. The slightest spark communicated to this tinder will be sufficient to occasion a commencement of combustion.

The Government of France has for some time been aware of the importance of attending to the preparation of charcoal for public use. The old method was discontinued several years ago, and the gunpowder charcoal has since been made in large trenches cut within the ground, and lined with brick, the superintendents of the gunpowder works having found that by this management the same kinds of woods will produce lighter and softer charcoal than when the wood is carbonized in large piles in the open air[36].

For philosophical experiments charcoal may be readily made by filling a large crucible with short pieces of wood, covering these with sand, and submitting the whole to a *red heat* for half an hour or more in a common fire-place. When I have had occasion to melt a block of tin, preparatory to making the nitrate or muriate of that metal, I have sometimes prepared very excellent charcoal by immersing pieces of wood in the melted metal, and holding them beneath the surface until the whole was charred entirely through. When this method is adopted, the charcoal may be plunged either into

petre. Therefore the tinder sold in the shops is not the simple female agaric, but a compound of that vegetable production and nitre.

[36] See Chaptal's *Chemistry applied to the Arts*, vol. ii. p. 288.

a vessel of mercury or a bed of cold sand, the moment it is drawn from the melting-pot, according to the purposes for which it may be wanted; and it will be found that by either of these modes it will be sufficiently preserved from the action of the atmosphere.

Whenever pieces of wood or other vegetable matters are charred without being disturbed during the operation, the grain of the wood and the form of the filaments are always preserved distinct and entire. If we examine writing paper or linen which has been covered up and burnt without the free access of atmospheric air, the wire marks of the paper and the threads of the linen will still be seen with distinctness.

When Sir William Hamilton explored the ruins of Herculaneum, he found corn that was converted to charcoal by the eruption of Vesuvius in the year 79 of the Christian era, and which was so well preserved that the grains of wheat were easily distinguishable from those of rye. We read indeed of some who have been so dexterous as to char an arrow without altering the form even of the feather[37].

On the contrary, if wood be burnt in the open air, the greatest part of it will be dissipated in gas. Common oak, if charred in a proper manner, will lose only from two-thirds to four-fifths of its weight; whereas if the same kind of wood be burnt in an open fire-place, the residuum of the combustion

[37] Neumann's *Chemistry*, by Lewis, vol. ii. page 277.

will not be more than about one 200th or one 250th of the original weight of the wood employed.

This, however, will vary according to the age and the dryness of the wood, and also to the different ways in which it may be burnt; and this accounts for the different statements which have been given of these results. Dr. Watson says that he procured 22 grains of charcoal from 96 of dry oak. Van Helmont, that 62lb. of the charcoal of oak will produce 1lb. of white ashes; whereas Sage says that 100lb. of charcoal will not give more than 2oz. of ashes.

The following table of the quantity of charcoal yielded by different woods, has been published by Mr. Mushet, from his own experiments in the small way, carefully conducted. He says, the woods before being charred were thoroughly dried, and pieces of each kind were selected as nearly alike in every respect as possible. One hundred parts of each sort were taken, and they produced as under:

Lignum Vitæ afforded	26.0	of charcoal of a grayish colour resembling coke.
Mahogany	25.4	tinged with brown, spongy and porous.
Laburnum	24.5	velvet black, compact, very hard.
Chesnut	23.2	glossy black, compact, firm.
Oak	22.6	black, close, very firm.
Walnut	20.6	dull black, close, firm.
Holly	19.9	dull black, loose and bulky.
Beech	19.9	dull black, spongy, firm.
Sycamore	19.7	fine black, bulky, moderately firm.
Elm	19.5	fine black, moderately firm.
Norway Pine	19.2	shining black, bulky, very soft.
Sallow	18.4	velvet black, bulky, loose and soft.
Ash	17.9	shining black, spongy, firm.
Birch	17.4	velvet black, bulky, firm.
Scottish Pine	16.4	tinged with brown, moderately firm.

Messrs. Allen and Pepys from 100 parts of the following woods obtained the quantities of charcoal as under:

Beech . . .	15.00	Oak . . .	17.40
Mahogany . .	15.75	Fir . . .	18.17
Lignum vitæ .	17.25	Box . . .	20.25

It is observable that the quantities obtained by Messrs. Allen and Pepys are in general less than those given by Mr. Mushet, which may be owing to Mr. Mushet not having applied sufficient heat, or operated long enough to dissipate the aqueous matter or the gaseous products. Charcoal was formerly considered to be a kind of *oxide* of carbon; but Messrs. Allen and Pepys have shown that this is not the case; and that when it is well prepared it requires as much oxygen for its complete combustion as the diamond[38].

To those persons who buy charcoal by weight, it is important to purchase it as soon after it is made as possible, as it quickly absorbs a considerable portion of water from the atmosphere. Different woods, however, differ in this respect. Messrs. Allen and Pepys found that by a week's exposure to the air, the charcoal of

Lignum Vitæ gained	9.6	per cent.
Fir	13.0	ditto
Box	14.0	ditto
Beech . . .	16.3	ditto
Oak . . .	16.5	ditto
Mahogany . .	18.0	ditto.

[38] *Philosophical Transactions* for 1807, part ii. page 267.

I have already adverted to the porosity of charcoal, page 392, and to the avidity with which fresh made charcoal absorbs all the gases. The following is a tabular view of the volumes of the different gases which were absorbed in the course of 24 hours, by one volume of charcoal, in the experiments of M. Theodore de Saussure [39], which were conducted in a way likely to produce correct results. Each portion of charcoal was heated afresh to a red heat, and allowed to cool under mercury. When taken from the mercury, it was instantly plunged into the vessel of gas.

Ammoniacal gas .	90	Bicarburetted hydrogen	35.00
Muriatic acid gas	85	Carbonic oxide . .	9.42
Sulphurous acid .	65	Oxygen gas . .	9.25
Sulphuretted hydrogen	55	Nitrogen . . .	7.50
Nitrous oxide . .	40	Carburetted hydrogen	5.00
Carbonic acid gas .	35	Hydrogen gas . .	1.75

I have already remarked, in another work, that a very interesting application may be made of this property of charcoal. The gases which are absorbed suffering so great a condensation, two gases introduced at once into the pores of the charcoal may perhaps be made to combine. Water has actually been formed from hydrogen and oxygen gases by this means [40].

Caspar Neumann, who made many experiments on charcoal, informs us that for the reduction of the metallic oxides, the charcoal of the heavier

[39] Thomson's *Annals*, vol. vi.

[40] *Chemical Catechism*, Additional Notes, No. II. *Annales de Chimie*, vol. xxxii.

woods, as that of the oak and the beech, is preferable, and that, for common fuel, such charcoal gives the greatest heat, and requires the most plentiful supply of air to keep it burning; while those of the lighter woods preserve a glowing heat with a much less draught of air; and that for purposes where it is desirable to have a steady and a still fire, charcoal should be employed which has been made from wood previously divested of its bark, since it is the cortical part which crackles and flies off in sparks during combustion, while the coal of the wood itself seldom does[41].

For making crayons of charcoal, the willow is the best wood that can be employed, as the softness is in all its parts uniform. The coals of the hard woods, such as box and guaiacum, are considerably harder than others, while the charcoal of the kernels of fruits is peculiarly soft and friable[42]. But as a pigment the coal of ivory is the most intensely black and the most beautiful. I speak here, not of the common ivory-black of the shops, but of the charcoal which is prepared by burning real ivory in closed vessels. As a powder for cleaning the teeth, the best charcoal is that made from the shell of the cocoa-nut.

The perfect durability of carbon as a pigment, may be seen in several of our old churchyards, where the letters made with lamp-black are still

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[41] Neumann's *Chemistry*, vol. ii. page 277.

[42] See Lewis's *Commercium Technicum*, page 337; also Dr. Grew *On the Anatomy of Plants*.

perfect, though the white lead with which the body of the stones was painted is entirely destroyed. Some few years ago I remember to have noticed this circumstance on Sir Hans Sloane's monument in the churchyard at Chelsea. This property of carbon is shown, however, in a more striking manner by the writings that were found in the ruins of Herculaneum, which have retained their original blackness for two thousand years. The ancients wrote with ink made from ground charcoal.

A friend of mine, who is engaged in refining rancid fish oil by means of tannin, has fitted up an apparatus for burning the gelatinous or leather kind of precipitate which results from his operation, and which he says is of little value for any other purpose. This charred powder, or soot, he informs me, proves to be a finer and better black for printers' ink and other purposes, than any he can procure by other methods. I think it would be worth while to try this gelatinous precipitate, when properly charred, in abstracting the colour from sugar, refiners' syrups, and certain valuable saline solutions, as it is well known that *animal* charcoal is much more efficacious for such purposes than any kind of *vegetable* charcoal.

The article known in commerce by the name of lamp-black, is carbon in the state of a light impalpable powder, and is procured by burning the refuse of resin and pitch in peculiar furnaces, with long flues terminating in a close chamber, the ceiling of which is covered with porous cloth, through which

the gas that is disengaged in the process may escape and the soot be left behind.

In drawing spirits of turpentine from the crude turpentine, there is a large residuum known in commerce by the name of *rosin*; and as a considerable portion is often found to be too impure to sell as rosin, it is profitably burnt for the production of lamp-black[43].

The coal of all resinous substances is of a similar nature. If lamp-black be heated red-hot in a crucible, and allowed to cool before the crucible be uncovered, we shall have, perhaps, as perfect a sample of pure carbon as can easily be prepared. Sir Humphry Davy says, "The purest known form in which carbon can be obtained, is by passing oils or spirits of wine through ignited tubes. It then appears as an impalpable black powder: it has no taste nor smell; it is a conductor of electricity, and it is more than twice as heavy as water[44]."

Some artists, for very nice purposes, have collected the carbonaceous matter which arises in burning the vegetable oils, by suspending some convenient substance at a proper distance over the flame of the lamp.

The beautiful brown pigment called *bistre* is prepared from an aqueous infusion of wood-soot.

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[43] Aikin's *Dictionary*, Art. Charcoal. A very particular account of this process may also be seen in Weigleb's *Chemistry* by Hobson, 4to. p. 540. A process somewhat different from this is described in the *Stockholm Transactions for the year* 1754.

[44] *Elements of Chemical Philosophy*, page 299.

Some account of its preparation is related by Lewis in his "Commerce of the Arts," but more ample directions for making it are given in the French Encyclopedia.

If it be required to purify any carbonaceous matter, to render it fitter for a pigment or other nice purpose, it may be done by first well calcining it in a close vessel, and then lixiviating it in water slightly acidulated by nitric acid. This process will separate the earthy or metallic particles with which it may be contaminated; and by heating it a second time in a very brisk fire properly secured from the air, we obtain a charcoal very near to the state of pure carbon.

Charcoal may also be obtained from animal substances burnt in closed vessels; but this differs from vegetable coal in some particulars, and, as I have already said, is better for some purposes. It is always more dense; and if it be made in a glass or earthen vessel, it adheres to it more than the carbon of vegetables; it is also less combustible, and generally contains phosphate of iron and other foreign matter.

It may be ascertained whether any carbonaceous matter be produced from animal or from vegetable substances, by the following trial. A *vegetable* coal will burn, on a red-hot iron, into white ashes, and these will be readily dissoluble by sulphuric acid into a bitterish liquor; whilst the ashes of *animal* substances are very sparingly affected by that acid, and form with it a compound having a very

different taste[45]. This fact is of importance to those sugar-refiners and others who use large quantities of animal charcoal in the state of powder, and which is often in danger of being adulterated with *vegetable* charcoal, an article that is not so efficacious, but is always to be obtained at a much lower price.

Charcoal is endowed with many singular properties, which cannot be too generally known, as some of them qualify it for rendering very important services to the arts. The intractable nature of carbon has been already mentioned; and whether coherent in charcoal, or in powder, is infusible by any heat that has hitherto been applied. "I have exposed it," says Sir Humphry Davy, "to the powers of intense ignition of different voltaic batteries; that of Mr. Children, one of 40 double plates of 18 inches square, and the battery of 2000 double plates of 4 inches, both in vacuo and in compressed gases, on which it had no power of chemical action. A little hydrogen was given off from it, and it slowly volatilized in these experiments, and the part remaining was much harder than before, so as in one case to scratch glass, and the lustre was greater; but its other properties were unaltered, and there was no appearance of fusion[46]."

It has been before mentioned, that charcoal is a bad conductor of heat; but I cannot avoid remark-

[45] Lewis's *Commercium Philosophico-Technicum*, 4to, 1763, page 377.

[46] *Elements of Chemical Philosophy*, page 300.

ing that few persons, comparatively speaking, have availed themselves of this property, although there are innumerable instances in which charcoal might be employed as a slow conductor of heat with very great advantage. The mention of a few of the most important of these must, however, suffice on the present occasion.

One of the most beneficial applications of charcoal, as a slow conductor of caloric, would be in some processes where it is necessary to preserve for a given time an equable temperature.

Thus, if all those vessels which are heated by steam, were made treble instead of double, and the space between the two outer vessels filled with ground charcoal, the heat would be so prevented from escaping, that any one particular temperature might be kept up for a great length of time, and a material saving of fuel would be accomplished. Guyton has shown that ground charcoal will conduct heat more slowly than even dry sand, and this in the proportion of three to two.

In extracting the colouring matter of dye-woods, and in making some other colours for the use of calico-printers, it is of great consequence to heat the vessels by steam; for by this mode of preparing decoctions the workmen are prevented from ever giving the materials a greater heat than that of 212°,—and the injury which was formerly done by the grosser matters burning at the bottom and sides of the copper, is avoided. Several manufacturers have now adopted this method, and I have lately

seen some apparatus in two or three establishments constructed on this principle, that appeared to me to be complete in every respect, excepting that they suffered much of the heat to escape; all of which might have been saved, and turned to a good account, by employing powdered charcoal in the way I have just described.

Again, whenever churches or other large buildings are to be warmed by steam, so much of the conducting pipe as is not actually within the building should always be surrounded in this manner: then no part of the heat could escape until it had been delivered within the space destined to be warmed by it.

In like manner, in the manufactories of starch, paper, gunpowder, Prussian blue, and a variety of other articles that might be mentioned, every part of the apparatus for drying these by steam, and which is not actually within the drying-rooms, ought to be secured in the same way.

The common steam-cooking apparatus and other culinary utensils would be much improved were they fitted with double covers, and the inner spaces between these covers filled up with charcoal-powder.

Moreover, by securing the conducting pipes in this manner, buildings might be effectually warmed, and processes conducted, at any distance from the site of the boiler, as "steam is the most faithful carrier of heat that can possibly be;" for it cannot deposit it on any bodies that have already acquired the temperature of 212°.

Owing to this non-conducting property of charcoal, it is very commonly employed in France to coat furnaces, and to confine the heat, for which its incombustible nature fits it in a peculiar manner[47], it being the most refractory body we know of, provided it be excluded from oxygen.

In domestic economy, charcoal is invaluable. From its property of retarding putrefaction it surpasses, as a preserver of meat, any thing we know of. Game, or any kind of animal food that has been over-kept, will be rendered perfectly sweet and wholesome by covering it with a few pieces of fresh burnt charcoal. Or, if it be far gone, boiling it for some minutes in water with a few ounces of such charcoal will effectually purify it[48].

How much better must the charcoal made in cylinders be for all these purposes than common charcoal! as the cylinder charcoal is free from the sap and acid of the wood, and consequently more tasteless in itself and lighter than the charcoal prepared in any other way. Those individuals who may be desirous of having such charcoal, may at any time procure it from the persons who manufacture either pyroligneous acid or gunpowder.

By its means also molasses or treacle may be de-

[47] Fourcroy's *System of Chemical Knowledge*, vol. i. p. 248.

[48] That water impregnated with carbonic acid gas is such an effectual preserver of meat, is probably altogether owing to the carbon of which this acid gas is composed. An interesting letter from Sir William Lee, Bart. to Dr. Priestley on this subject, will be found in the Appendix to the fourth volume of the Doctor's "*Observations on Air.*"

prived of its disagreeable taste, so that it might be used in families instead of sugar. M. Cadet Devaux says that he diluted twenty-four pounds of treacle with the same weight of water, and boiled it for half an hour with six pounds of pulverized charcoal, which entirely deprived it of its empyreumatic taste and smell. He then strained the saccharine liquid from the charcoal; and, having evaporated it to a due consistence by a gentle heat, found its flavour equal to that of good sugar. Those who have occasion to use honey, and yet have an objection to its peculiar flavour, may deprive it of this taste by a similar management.

The principle of refining sugar by means of charcoal is indeed the basis of the patent taken out by Mons. Cronstat, and for the transfer of which he required of the joint body of sugar-bakers in London a remuneration of fifty thousand pounds: and I have reason to think that the proprietors of a small concern established only a few years ago in the metropolis, where double loaves are manufactured of a finer quality than are produced at any other house, effect the purpose by the same means.

In like manner the disagreeable empyreumatic flavour which some brandies acquire in distillation, may be removed by digesting them on charcoal; and common malt-vinegar, if boiled on charcoal, becomes quite colourless like distilled vinegar, without being impaired in strength; whereas it always becomes much weaker by distillation.

On the same principle charcoal is frequently employed by the manufacturing chemist in purifying any of the salts which may have become coloured from accidental circumstances, or from their combination with heterogeneous matters. It is only necessary to redissolve them, and boil their solutions on charcoal, and when re-crystallized they will be found pure and colourless[49].

Even the common salt of hartshorn, (carbonate of ammonia,) which is prepared from a liquor distilled from bones, and which often requires great labour to render it of the desired purity, loses the whole of its fœtid smell by being mixed with charcoal powder, and re-sublimed.

On long voyages the water, which has been laid in for the ship's crew, generally acquires a disagreeable taste and smell from standing so long in the wooden casks; but whenever this happens, it can be entirely purified by filtrating it through ground charcoal. It is always best, however, to send out water in casks that are charred within side, as water kept in such casks is always sweet. In London and elsewhere, it is very common to pitch water-casks on the whole of their inner surface; but surely it would be cheaper, and much more effectual for

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[49] M. Lowitz has published a method of purifying the citric, succinic, and benzoic acids, by means of charcoal powder, and at the same time directs how the salt known by the name of acetate of potash may be rendered whiter than ordinary by the use of the same intermedium.—See Crell's *Chemical Annals for the year* 1793, and *Annales de Chimie*, tome xix. page 367.

making them into good water-casks, to light a fire of wood-shavings within them, and keep it burning until the whole of the surface on the inside is completely charred.

It is difficult to understand how charcoal acts, so as to purify so many vegetable and animal substances, and to remove the colour and the noxious taste and smell of such a variety of articles, and in such a variety of states and cases: but as charcoal has the property of absorbing all the known gases, and condensing them in its pores [50] in quantities far exceeding its own bulk [51], to this the effect is probably due.

That these processes may always answer, it is necessary that the charcoal should be fresh made, or that it should be heated red-hot under a cover of sand immediately before it is used; and that in nice operations the necessary quantity should be ascertained by previous experiment; for, if too much be employed, the articles on which it is intended to operate will sometimes be decomposed, especially if heat be applied; and if a sufficient quantity be not taken, the effect will be produced

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[50] Some interesting disquisitions on this subject may be seen in the *Journal de Physique for* 1783; in the *Annales de Chimie*, tome xxxii.; in Murray's *Chemistry*, second edition, vol. ii. page 486; and in the 26th number of *The Journal of Science, Literature, and the Arts*, from M. A. Bussy's Memoir in the *Journal de Pharmacie for June* 1822.

[51] Morozzo's experiments on the quantity of the different gases absorbed by charcoal, may be seen in the *Journal de Physique*, an. 12.

only partially. M. Lowitz, who has pursued this subject further than any one else, has given some very important directions, which are necessary to be attended to by those who employ this substance as an article of purification in any manufacturing processes [52].

In some cases it is necessary to use it in a pulverized state; but in all these instances it should be pounded immediately from the fire, before it is exposed to the air; and what is not used should be preserved in glass bottles closely stopped, on account of the property it has, as we have already seen, of absorbing water and the gases in abundance.

In addition to the experiments of Messrs. Allen and Pepys, M. Chaptal has shown, that charcoal absorbs 15 or 20 per cent. of water from the atmosphere, while cooling, and that soft coke acquires 25 per cent. of water in the same time [53].

Besides those which have been already mentioned, charcoal has many other uses in the arts. It is used by mathematical instrument makers and engravers to polish brass and copper plates; by horners in polishing lanthorn-leaves; and by artists for tracing the outlines of drawings. On account of its powerful affinity for oxygen, it is employed by the makers of glass and by soap-boilers and others, in decomposing many of the neutral salts called

[52] These directions will be found in Crell's *Chemical Journal*, vol. ii. page 270.

[53] Chaptal's *Elements of Chemistry*, vol. iii. page 199.

sulphates, so as to enable them to use their alkaline bases in the room of barilla and potash. More of this, however, will be found in the second volume, in the Essays on the fixed alkalies and on glass.

Charcoal is employed also by the makers of *coloured* glass to communicate some peculiar tints of brown and yellow to their artificial gems. The late Mr. Samuel Moore, who was many years the Secretary to the Society for the Promotion of Arts, Manufactures and Commerce, made an extensive series of experiments on this subject. Some account of his processes may be seen in the "*Commercium Technicum*," published by his friend Dr. Lewis [54].

In connexion with this subject, I am desirous of suggesting whether the tar which precipitates from pyroligneous acid, if judiciously employed, might not furnish these manufacturers with coloured glass possessing some original tints; for, on visiting an extensive charcoal-work, where the cylinders are erected within a very capacious building, I observed that the vapours which escaped during the distillation had coated the glass in the windows of a very lively colour between brown and orange.

On the Continent, it is a common practice to char one end of all the posts or other timbers which are to be fixed within the ground; and if this be carefully and properly done, and so much of the

[54] See *The Commerce of the Arts*, London, 1763, page 628, &c.

timber be charred as is to be covered with the soil, it will be rendered imperishable, or at least it will last much longer than the parts above the ground which have not been charred. Indeed charcoal is perfectly incorruptible if buried in the earth; therefore the deeper the surface of the wood is charred, provided enough be left to give sufficient strength to such posts, the more effectually will they be preserved.

This method of charring timber is already practised in some parts of England; and being convinced of the economy and efficacy of the practice, I mention it here with the hope of rendering it more general. All that is necessary is to light a fire upon the ground, which should be surrounded with a wall built with loose bricks or stones, and then, when the pieces of timber are laid across the walls, to have a contrivance to turn them regularly round so as to present every part to the action of the fire in succession; and when the whole surface to the depth of three quarters of an inch or an inch is converted to charcoal they will be sufficiently prepared. While charring, they should have a temporary covering of green boughs or other matter to preserve them from the action of the atmosphere, which would be apt to convert part of the wood into ashes.

The incorruptibility of charcoal was well known to the ancients, and they availed themselves of this property on all important occasions. Of this we have abundant evidence.

In making the foundation for the temple of Diana at Ephesus, more than two thousand years ago, it was necessary to drive piles; and when some of these were taken up of late years it was found that they had been charred. Again, it has been stated that "about sixty years ago a quantity of oak stakes were found in the bed of the Thames, in the very spot where Tacitus says that the Britons fixed a vast number of such stakes, to prevent the passage of Julius Cæsar and his army. These stakes were charred to a considerable depth, had retained their form completely, and were firm at the heart[55]."

That it is actually possible to render wood indestructible, will appear from the recollection of the process of nature usually called petrifaction. About seventy years ago, one of the timbers that supported the bridge which the Emperor Trajan threw over the Danube a little below Belgrade, was taken up, and the outer part to the depth of half an inch was found to be converted to an agate, the inner parts were slightly petrified, and the central were still perfect wood, though this timber had been in the water 1700 years[56].

There are few collections of minerals that do not contain some specimens of wood thus mineralized; and in the Emperor's collection at Vienna there are many pieces converted more or less into agates of various colours. Among them there are billets of

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[55] Dr. Robison's *Introduction to Dr. Black's Lectures.*
[56] Kirwan's *Geological Essays.*

half a foot or a foot in diameter thus petrified, and capable of taking a very fine polish. One of these is agate at one end, and retains its ligneous nature at the other.

In the History of the Academy of Sciences at Paris for the year 1763, is an account of Mr. Moll's cabinet of minerals, which is very effectual towards the conviction of those who deny the possibility of wood being thus agatized. The comparison which this eminent collector has made between certain woods and plants said to be petrified, and the same kinds of bodies in their natural state, seems to put this matter out of dispute.

Having made a large collection of wood that was converted into agate, he sawed off the thinnest laminæ possible from many of the pieces, and after polishing them he examined them by the microscope, and perceived plainly the difference of texture in the different specimens. It was observable that one of these was doubtless fir, another reed, or some aquatic plant of that class; and on examining shavings or small pieces of the wood to which he supposed the specimens belonged, it was impossible to resist the evidence furnished by this comparison. In both sets of objects the same direction of the longitudinal and transverse fibres of the wood is perceived, and the same arrangement of the vesicles [57].

In returning from this digression, it may be re-

[57] More on this subject may be seen in the *Appendix to the Monthly Review*, vol. xxxvi. page 557.

marked that it were much to be wished that the English builders would adopt the practice above mentioned, and char every piece of wood before it is placed within the ground. Several years ago Dr. Watson suggested the propriety of charring all the wood used in mines and subterraneous drains, and particularly that employed in the covering of soughs, through which there is a current of water, and which rots in a few years by the alternate change of wet and dry[58]. I would remark, in addition, that if this had been the general practice, many sad accidents which happen from the breaking of such timbers would have been prevented, and some lives saved.

Most of the houses in Venice stand upon piles of wood, which have all been previously charred for their preservation[59]. In this country, estates were formerly marked out by charred stakes driven to a considerable depth under ground.

It is perhaps worth mentioning, "that when old chesnut, or other trees, are rotted within the trunk, and threatened with speedy destruction by the progress of the carious taint, it may be stopped by applying fire to the decayed part, so as to char the whole of the neighbouring surfaces[60]." By this management the life of a favourite tree may often be preserved.

In enumerating many of the uses of charcoal, I

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[58] Watson's *Chemical Essays*, London, 1789, vol iii. p. 48.
[59] See Platt's *Jewel House of Art and Nature*, page 25.
[60] See Chaptal's *Chemistry applied to the Arts*.

have hitherto omitted to mention its employment in the manufacture of bar-iron, and the conversion of iron into steel; to the perfection of which, both the one and the other, wood charcoal is, I believe, essential. Formerly, all the wrought iron that was made in this country was manufactured with charcoal; but as wood became scarce, and the Government restricted its use, the iron-masters gradually introduced the use of cinders and coke, and now most of the bar-iron which is made in these kingdoms is prepared chiefly by the latter methods. This, however, has reduced the quality of the English iron so much, that, for many purposes, the artificer is under the necessity of employing Russian and Swedish iron, which is all prepared by means of the coal of wood.

Mons. Hassenfratz is of opinion that the superiority of the iron which is made with charcoal, is owing to its combining with a portion of *potassium*; and when it is considered how great is the difference between iron and steel, and how small is the quantity of carbon that produces this difference, it may easily be believed that the potassium of the wood is capable of effecting the change in question [61].

The ores of iron are very abundant in this country, and for some hundred years had been worked to a great extent for the production of this metal; and as nothing was at first used for the reduction of

[61] Nicholson's *Journal*, xxv. page 51.

these ores but wood-charcoal, the consumption of wood became so enormous that the legislature thought it advisable to interfere, and prevent its indiscriminate use.

By the act of the 1st of Queen Elizabeth, chap. 15, it was enacted, that no oak, beech, or ash timber, of the breadth of one foot square at the stub, should be cut down to be converted to charcoal for making of iron, in any part of the kingdoms of England and Wales, except in the county of Sussex, in the weild of Kent, and in certain parishes therein named in the county of Surry.

Notwithstanding this enactment, the makers of iron gave up the use of charcoal with great reluctance, as they imagined that it was impossible to make useful malleable iron without charcoal.

However, about the middle of the last century some few iron-masters acquired the habit of making bar-iron with the coke of pit-coal, prepared from a particular sort of coal, and in a manner which was kept secret from their competitors in the trade.

In the year 1773 Mr. Henry Horne published his "*Essays on Iron and Steel*," with directions for reducing the common iron ore, by means of coke, into pig-iron, and then into bar-iron, fit for the most curious purposes; and in the same work he gave directions for a more perfect method than any before known, of charring pit-coal, so as to render it a proper succedaneum for wood-charcoal in the manufacture of iron. This little volume is now become scarce: it contains, however, many interest-

ing particulars, and is, I think, worth the perusal of those who are engaged either in making iron or steel.

Since the publication of Mr. Horne's book, the coke of pit-coal has been brought into more general use, so that, at this day, many thousand tons of coal are annually converted into coke, not only for the purpose of making iron, but for various other employments connected with the trade and manufactures of the country.

The coke of pit-coal is used largely in the drying of malt, and in the fires of a variety of artists, to whom the smoke of pit-coal would be injurious; in refining gold and silver; and in the smelting of metals. In the preparation of this coke, the fuliginous, bituminous, and sulphurous parts of the coal, which would give a taint to the malt, and a brittleness to the metals, are dissipated, whilst the more pure and carbonaceous matter is left [62].

The consumption of coke is now so considerable, that within these few years great attention has been paid to the selection of the best kind of pit-coal for its preparation, and to the improvement of the ovens in which the operation is performed. Those in the neighbourhood of Sheffield, belonging to the Duke of Norfolk, are the best which I have seen [63].

[62] See some further observations on this subject in Lewis's *Translation* of *Neumann's Chemical Works*, vol. ii. page 277.

[63] A very particular description of these ovens will be found in the Additional Notes to the *Chemical Catechism*, No. 50; and also in the description of the plates to the present volumes.

It has been usual in the large iron-works to prepare the coke without ovens, merely by making large piles of common coals in the open air, somewhat similar to that mode of making wood-charcoal described at page 395, and setting fire to these heaps at different places at the same time; and when the mass appears to be thoroughly lighted, to cover or smother up, as it is called, the whole heap with dust. In this state the combustion is continued until all the coal is converted into coke.

A new method of making coke has, however, of late years been adopted at an extensive iron-work in the neighbourhood of Chesterfield, which has been found very advantageous.

For this purpose a substantial brick-chimney is built on an open space of ground, and the coal is piled round it. When the pile is constructed, instead of lighting it in different places on the outside of the heap, a quantity of ignited coal is thrown down this brick-chimney; which being built upon arches, the fire readily communicates through them to those parts of the pile which are immediately contiguous to the chimney, so that the fire commences in the *middle* instead of at the *outside* of the heap, and soon spreads through the whole mass. When sufficiently burnt, and partially cooled, the heap is broken into, and the whole is quenched by water.

The coke thus prepared is so much better than that which is produced in the common way, that a less proportion of it is sufficient for making any specific quantity of iron.

This enables the blast-furnace to hold an additional charge of iron-stone, and consequently the manufacturer can run considerably more pig-iron at every operation. The annual saving which this has occasioned is, I understand, far exceeding that which the proprietors themselves had expected; for, the quantity of the coke produced is much greater from a given measure of the coals, and, what is of still greater importance, the iron is of a much better quality.

The proprietors of these works, who deem this new method of cokeing to be a most important improvement in their manufactory, consider the cause to be totally inexplicable.

To hazard a conjecture, respecting the nature of this obvious improvement, I should certainly attribute all these advantages to the chimney, which from the nature of its construction occasions a constant draught of air through the whole body of the burning materials, and carries off all the gaseous products which would otherwise be absorbed by the coke, and impair its quality; similar to the injury which the wood-charcoal received by stopping up the vent-holes, as related at pages 402—405 of this volume.

Having given an ample account of the preparation of charcoal, and of the uses to which it is applied, and also of the various compounds which have been formed by its means, it will now be proper to speak of the principal *natural* productions which contain carbon as one of their component parts.

Of these we have native mineral carbon and carburet of iron, besides the diamond already treated of; and a great variety of minerals containing carbonic acid as one of their component parts, such as carbonate of lime including chalk, limestone marble, calcareous spar, slate spar, satin spar, lucullite, and several others; of some of which there are vast mountains in various parts of the world; Witherite, or carbonate of barytes; strontianite, or carbonate of strontites; natron, or carbonate of soda, besides others which might be mentioned: but as it would extend this Essay to too great a length to describe all these productions of Nature, I shall content myself with offering a few remarks on some of the varieties of mineral coal, of all which the basis is carbon.

Mineralogists in their classification of coals have divided the whole into four species, very distinct from each other; viz. plumbago, or the *graphite* of Werner, which is a carburet of iron; the *anthracite* of Haüy, or, as it is more commonly called, *anthracolite*; jet and cannel coal; and all the varieties of common pit-coal.

Plumbago, usually known by the very improper name of black-lead, occurs in some particular spots in most countries in the world. It is well known as the article of which pencils are made [64], and is

[64] From a remark of Sir John Pettus, I imagine black-lead pencils have not been in use more than 150 or 160 years. "*Of late*," says he, speaking of black lead, "it is curiously formed

found in various situations, such as in the midst of mountains, in beds of quartz, and in masses of calcareous earth. It generally occurs in kidney-form lumps of various dimensions from the size of a pea to pieces of some considerable weight. Its specific gravity is about twice that of water; though Dr. Freind states it to be only 1.714, and Boyle 1.860. When pure, it consists of about ninety-five parts carbon and five of iron. Hence, as might be expected, it is as incombustible and indestructible as charcoal, unless heated with atmospheric air[65]; there is, however, considerable difficulty attending the analysis of this mineral, from certain causes which have been pointed out by Mr. Brande[66]. Some kinds of plumbago are very impure. Vauquelin has given the analysis of a French specimen which contained only 23 per cent. of carbon, 2 of iron, 38 of silica, and 37 of alumina.

To the modern methods of analysis we are entirely indebted for a knowledge of the nature of this substance. Camden, our celebrated historian, calls it "a metallic earth, or hard glittering stone, used by painters to draw with. Whether," says he, "it be *pnigitis*, or *melanteria* of Dioscorides, or ochre burnt black by the heat of the earth, I cannot determine[67]."

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into cases of deal, or cedar, and so sold as dry pencils, something more useful than pen and ink." Sir John Pettus's *Fleta Minor*, folio, London, 1686, article *Lead*.

[65] It is this property which renders plumbago one of the best substances in nature for the fabrication of those crucibles which are designed to resist the most intense heat.

Boyle calls it "a mineral *sui generis*, approaching to a talc," and says that "it has nothing metallic in its nature[68]." The ingenious Scheele was the first person who pointed out the real nature of this mineral. He showed that by burning it in a peculiar manner it might all be converted into carbonic acid gas, except a small residuum, which he found to be iron[69].

The finest plumbago that has ever been discovered is procured from a mine at Borrowdale, about six miles from Keswick, and in the neighbourhood of the lofty mountain of Skiddaw, in the county of Cumberland. I know of no other mine which produces this mineral in a state fit for making good black-lead pencils: it is on account of its excellency therefore exported to all parts of the world[70]. The superior quality of this article is indeed so generally allowed, that on the continent the pencils made with it are called *crayons d'Angleterre*.

Plumbago has within these few years been found of tolerably good quality, and in very considerable quantities, in an estate lying about seven or eight miles north of the town of Ayr in North Britain. In some parts of that neighbourhood it occurs at the surface of the ground. It has been discovered

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[66] Brande's *Manual*, vol. ii. page 121.
[67] Gough's edition of Camden's *Britannia*, folio, vol. iii. 170.
[68] Boyle's *Works*, vol. v. page 27.
[69] Scheele's *Chemical Essays*, page 243.
[70] According to Dr. Campbell, this mineral is used with great success by dyers in fixing blue colours, vol. ii. page 38.

also at a considerable depth at the foot of the mountains in the island of Ceylon[71].

Dr. Campbell, in his Political Survey of Great Britain, speaking of the Borrowdale mine, says that this mine is private property, that it is opened but once in seven years, and no greater quantity than is equal to the consumption is allowed to be sold. At the mine it is called *wadd*, and those who are concerned in raising it suppose it to be impregnated with lead and antimony. Dr. Campbell considered it to be a mixture of talc and zinc[72]. When this mineral was first raised, it was employed for marking sheep. It was afterwards used in medicine, for disorders of the bowels, and in nephritic complaints[73].

Although the mine at Borrowdale may alone produce plumbago fit for making the best sort of pencils, there are many other places where this mineral is to be found, and sufficiently good for all other purposes. At present it is applied chiefly to the following uses.

It is employed to make crayons and black-lead pencils; to cover the best sort of iron castings to give them a shining coat, and preserve them from rust; to give a polish to small leaden shot; to rub on the cogs of wheels and other machinery, in order

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[71] Cordiner's *Description of Ceylon*, 4to. 1807, vol. i. page 13. Knox's *History of Ceylon*, folio, page 31.

[72] *Political Survey of Great Britain*, London, 1774, 4to, vol. ii. page 37.

[73] *Philosophical Transactions*, No. 240, page 183.

to diminish friction, and impart smoothness and lubricity to the parts which have most wear; to mix with potter's clay for the production of some particular sorts of earthenware; to make crucibles and other utensils which are to undergo intense heats; and, when kneaded with clay, to line all sorts of portable furnaces which are designed to be used in the reduction of ores and other chemical operations.

The natural incombustibility of plumbago peculiarly fits it for other purposes to which it has not yet been applied in this country; but especially for the covering of certain parts of wooden buildings to preserve them from accidents by fire.

It is lamentable to perceive with what facility and success some people impose upon the public. Even the article of plumbago has been employed for purposes of quackery. The following is the substance of the specification of a patent, dated the 6th of June 1812, for what the patentee calls his "Anti-Attrition Paste." It is merely that 1 cwt. of plumbago be mixed with 4 cwt. of pork-lard, or with a like quantity of suet, or of some one of the other articles enumerated in the specification[74]. Surely this patentee could not be ignorant of the fact that such a mixture had long been used for similar purposes prior to the date of his patent, particularly in many of the manufacturing counties.

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[74] See *The Retrospect*, No. 34; or *The Repertory of Arts*, No. 130.

In order, however, to expose this pretension to originality the more effectually, the following recipe is selected from a printed volume, which may be had of any of the principal booksellers in London or elsewhere. "Mix one pound of hog's lard with half a pound of black-lead; stir them well together, whilst melting over a slow fire. If the axles and bushes of the wheels be true, a carriage may safely be run one hundred or one hundred and fifty miles, with once using the above composition [75]."

Some time ago, a gentleman, a native of the state of North Carolina, informed me that a mine of black-lead had been discovered in the neighbourhood of Raleigh, one of the cities of that state, which promises to be of very considerable consequence to the whole of North America. The mineral occurs in large solid lumps, and the mine is so extensive that it is thought to be inexhaustible. It is usually sold in its native state, packed in barrels, at 18*s*. or 20*s*. per cwt.

This native carburet of iron is used very extensively in the state of North Carolina for a variety of purposes. They grind it with oil for painting the wooden roofs of their houses and even their best buildings. It is found to answer extremely well for preserving the wood from decay, and for keeping out the rain; and it is a great preservative against fire.

In America, where most of the fires are made

[75] *The Family Receipt Book*, Murray, London, 1811, p. 414.

with wood, accidents often happen from the circumstance of the sparks setting fire to the wooden roofs of their houses, and occasioning dreadful conflagrations: but this can never occur to those roofs which have been treated in this way; for I learn that the wooden shingles, which have been painted with two or three coats of this preparation, have been purposely exposed to the full heat of a large fire for a considerable time, without their sustaining any injury.

This seems rather extraordinary, as one would have imagined that the oil would have still retained its combustible properties. It may, however, be a circumstance well worth the investigation of those who have it in their power to procure plumbago at a cheap rate.

On a journey to the lakes of Westmoreland and Cumberland, in the summer of the year 1814, I heard that the celebrated mine of black-lead in Borrowdale had been lately opened, and that the workmen were then engaged in raising and dressing the mineral. Rejoiced at this intelligence, I immediately determined not to lose so favourable an opportunity of visiting this curious spot, and therefore fixed myself at Keswick, the nearest town to the mine, in order to collect the necessary preliminary information, and learn how to procure the most intelligent guide which the neighbourhood could afford. In travelling from the north, the road lies thus:—From Carlisle to Wigton is 11 miles; from thence to Keswick is 22 miles; and

from Keswick to the mine 9 miles. From Keswick to the mine saddle-horses are necessary, as some of the defiles through the mountains are too narrow to admit the passing of a carriage. As no account has hitherto been given of this celebrated mine, where black-lead is found of a quality far superior to what is known in any other part of the world, I trust the following particulars will not be uninteresting to my readers.

The neighbourhood of Keswick has for ages been celebrated as a mining country. In the reign of Queen Elizabeth, gold and silver were procured in considerable quantity from the mountain called *Gold-scarpe* in the vale of Newlands near Keswick. At that time the mine was worked by a company of Germans, who raised a large quantity of copper and lead, and not only converted these to their own use, but also laid claim to the precious metals, in opposition to the Queen, who demanded them as well as the usual royalty. However, on an appeal to common law, her majesty gained the point, and the foreigners soon after absconded.

It was during this reign that the very valuable mine of black-lead was discovered. The inhabitants of the neighbourhood say that this rich depository was first brought to light by a tremendous hurricane, which blew up a large ash-tree and discovered a mass of fine plumbago at its root. The mine now at work is in the midst of a mountain which chiefly consists of slate and that species of rock called *grauwacke*; it is about 2000 feet high,

it rises at an angle, as near as I could guess, of 45 degrees, and is situate among other stupendous hills in a district known by the name of *Borrowdale*. When the value of this mine became known, the proprietors found it very difficult to guard it so as to prevent depredations. The practice of robbing it was become so common, that several persons living in the neighbourhood were said to have made large fortunes by secreting and selling the mineral: this, however, is now entirely prevented by some expedients hereafter to be mentioned. Even a guard stationed on the spot was of little avail, for 70 or 80 years ago a body of miners broke into the mine by main force, and held the possession of it in spite of the proprietors themselves. At one time the depredations had arrived to such a pitch, and so great was the quantity which had been stolen, that the delinquents were actually able to deprive the proprietors of their regular customers, by lowering the price of the article in the London market. This circumstance so annoyed the original company, that at last they thought it expedient to buy up the whole stock that remained in the hands of the robbers, as the only way of putting an end to the competition. It is not many years since a very large quantity of fine black-lead was found on Vickers Island, situated in Derwent-water; and it is supposed that this was secreted there at the time the robbers had possession of the mine in Borrowdale.

It has been already mentioned that the black-

lead mountain has an altitude of about 2000 feet; and as that part of the mine which is now working is near the middle of the mountain, the present entrance is about 1000 feet from its summit. There are indeed two entrances; a small one by which the workmen descend by means of a flight of steps; the other is a large horizontal one capable of admitting hand-carts and wheel-barrows for the removal of the rubbish and loose earth by which the black-lead is enveloped; and through this entrance the water passes off which constantly runs through the mine.

In order to secure the vast treasure which is contained within this mountain, the proprietors have now erected a strong brick building, consisting of four rooms on the ground-floor, one of which is immediately over the opening by which the workmen enter the mine as they go to their work. This opening is secured by a trap-door, and the room connected with it is called the dressing-room; for, when the men enter it, they strip off their usual clothes, and each of them puts on a dress suitable for working in a mine. The men work six hours each, and then they are relieved by others. When the hour of relief comes, the steward attends in the dressing-room, to see the men undress, as they come up the steps one by one out of the mine, when they put on their usual clothes, which are also examined by the steward to see that they have no black-lead concealed within them. This room contains no furniture except the pegs on which the

clothes are hung, and which extend all round the room, each man knowing his own. When these have dressed and departed, another set of men clothe themselves for their work and enter the mine as before; the trap-door is then again shut, and the steward is relieved to attend his other occupations.

I have said that the house consists of four rooms, and these are contrived so as to be connected with each other. In the innermost of these rooms there is a kind of counter or strong table, under the window, at which two men sit who are constantly employed in assorting and dressing the mineral. This is necessary, because it is usual to divide the black-lead into two kinds, called best and coarse; and as the finest specimens have generally pieces of iron-ore or other impurity attached to them, these are dressed off by peculiar tools adapted to the purpose. These men are constantly shut in when at work, and the steward walks backwards and forwards in an adjoining room furnished with two loaded blunderbusses, which hang within his reach, for the sake of further security. As the black-lead is cleaned, it is put into firm casks which hold about 112lb. each, and these are sent by waggon to the warehouse of the proprietors in London. Formerly this mine was opened only once in six or seven years, as I have before said; but in consequence of the demand being greater, and the quantity which they have discovered not being so large, it has been found expedient to open the mine, and dig for the ore during six or seven weeks in every year. At

this time the mine is guarded night and day; and it is thought necessary that the steward, who only lives at the village of *Seathwait* at the foot of the mountain, should not leave the house at any time during the whole of this period, except an hour or two on the Sunday to visit his family, and even then, as he told me, he was always careful to return to his dwelling on the mountain while it was yet day-light. In consequence of the mine having of late years been opened every summer, they now raise all the black-lead they find, and then the mine is securely shut up in the following manner:—The workmen wheel back the rubbish which had been removed at the opening of the mine, and this is laid in one continued heap, to the amount of some hundred cart-loads, which securely blocks up both the passages into the mine. The door is then locked, as well as the door into the house, and all the men then leave the premises in a state of safety; for the mass of rubbish which is thus wheeled in at the larger door, dams up the small rill of water which usually flows through the mine, and this has the effect of flooding it completely. Thus, if an attempt were made to break the house and enter the mine by that road, the robbers would find that the water had arisen to such a height as would drown any individual who should attempt to search for the ore.

From an examination of the exterior of the mountain, it appears that in former times various small shafts have been sunk for getting the black-lead; and the mine which they are now working was

one of those which had been closed for a century, but was again opened in the year 1769, in consequence of another mine in the immediate vicinity having failed. The expense of raising the black-lead varies very much in different years, according to the size of the masses which the workmen happen to meet with: for instance, that which they found in the year 1778 was four yards in diameter, and twelve yards high; that of 1803 was twenty-one yards and a half high, two yards and a half in diameter, and perfectly round like a column; that which they found in 1812 was rather less than twenty yards in height, and only two feet in diameter; and what they are now getting is found only in a narrow string. The expenses of driving the level, of building the house, and working the mine, from the 23d of April 1798 to the 4th of April 1814, have amounted to 6637*l.* 9*s.* 4*d.*; and during this period there have been produced 736 casks of fine black-lead, and 1816 casks of the coarse kind, amounting together to 2552 casks of about 112lb. each.

It might be a matter of difficulty to those who visit the mine, to conceive how these casks of black-lead can be conveyed with safety down the face of so steep a mountain. This is done by men who have been long accustomed to the task. The cask is fixed upon a light sledge with two wheels, and the man, who is well used to this sort of precipitous path, walks coolly down before the sledge, taking care that it does not acquire too great a momentum,

and thus overpower him. The empty sledge he then carries back upon his shoulders, and takes another cask. All the black-lead is sent to London, as I have already mentioned, where it is deposited in the warehouse of the proprietors, and afterwards disposed of by public auction held at Essex-street in the Strand, London. This happens on the first Monday of every month throughout the year; and the best kind usually sells for two guineas or more per pound. There are some considerable manufactories of pencils at Keswick, but I was told that the makers are under the necessity of sending to London for all the black-lead they use in the trade, although they reside so near the place of its production.

The propriety of this valuable mine is divided, as I understand, into two equal parts, one of which belongs to Henry Bankes, Esq. representative in parliament for Corfe Castle in the county of Dorset; and the other moiety is divided into ten or twelve shares belonging to the executors of the late Sir Joseph Banks, Sir John Mitford, the executors of the late Mr. Gilbert, and others. In some years the net produce of the black-lead has amounted to thirty or forty thousand pounds. Mr. Otley has stated, that by an account drawn up in 1804 the stock of black-lead then on hand was valued at 54,000*l.*, and the annual consumption about 3500*l.*; the best black-lead was then sold at 35*s.* per pound; since that time the price has been from 30*s.* to 45*s.* and the consumption is much increased. It is re-

markable that this mine, which was valued in making the grant of the manor of Borrowdale by King James I. at 15*s.* 4*d.*, was on the last assessment for the property tax, estimated at 2700*l.* sterling a year. Some other particulars respecting this singular mine may be seen in the works quoted below [76].

The second kind of coal, which is called anthracolite, is seldom found but in the primitive mountains. It is generally amorphous, but sometimes occurs in a crystallized form. It is what is called incombustible coal, and by Werner glance-coal; and as it contains more carbon than most of the common pit-coal, it may with propriety be classed next to plumbago. It burns slowly and without flame; its specific gravity varies from 1300 to 1500. This species, which is composed of 64 carbon, 33 silica, and 3 parts of iron, is not considered by some mineralogists to be of vegetable origin.

The third kind of coal mentioned above, is jet and cannel coal. Both these varieties Werner denominates by the name of *black coal.* They are found in many parts of the world, and are often

[76] Robinson's *Natural History of Westmoreland and Cumberland,* 8vo, London, 1709, page 75; Colonel Thornton's *Sporting Tour through the Northern Parts of England,* 4to, London, 1804, page 282; Mr. Otley in *Memoirs of the Literary and Philosophical Society of Manchester,* second series, vol. iii. pages 168—175.

used in forming ornamental trinkets, particularly in France, where they occur in abundance. The cannel coal acquired its name from the property it has of burning like a candle; for in the Lancashire and Scotch dialect candle is pronounced *cannel*.

In Scotland this bears the name of parrot-coal. It does not cake in the fire; and though it flames like a candle in the beginning of its combustion, this lasts but for a short time, and the residuum is considerable. The specific gravity of this coal is from 1.234 to 1.250. A specimen of the Lancashire cannel coal analysed by Mr. Kirwan contained 75 per cent. carbon, 22 maltha, and 3 alumina and silica.

The fourth species includes all the varieties of the common pit-coal. These are composed of bitumen, carbon, and heterogeneous matters in different proportions, according to the places from whence they are procured. Some of these are black and ponderous, and, from the quantity of bitumen and sulphur which they contain, burn very freely, and give out a great heat, though the combustion is of short duration. This sort generally contains a large admixture of martial pyrites, which sometimes occasions spontaneous combustion when they are laid in large heaps, and are exposed to the affusion of water[77].

[77] See the Essay on Temperature, page 105; and for a more detailed account of the several varieties of martial pyrites, consult Henckel's *Pyritologia*, 8vo, London, 1757.

There are other coals that burn very freely, which cake into a mass when laid on the fire; these burn without any sulphureous smell, and leave no residuum but a very inconsiderable quantity of ashes.

Respecting the specific gravity of coals, the accounts which I have seen vary in themselves as much as they do from the results which I obtained. Mr. Charles Labelye makes the specific gravity of Newcastle coal to be 1.270. Boyle gives the specific gravity of Scotch coal 1.300. The Oxford Philosophical Society states the specific gravity of pit-coal from Staffordshire to be 1.240. Mr. John Caswall makes the same coal to be 1.238. The Philosophical Society at Oxford found a cubic foot of pump-water to be 62½ pounds avoirdupoise; the same measure of Staffordshire coals 63 pounds; and of Newcastle coals 67lb. 12oz.[78] Kirwan[79] gives the specific gravity of six species of coal which vary from 1.232 to 1.357. A specimen of slate-coal he found to be as high as 1.426.

There is a peculiar kind of hard coal raised at Pontetaive, a few miles from Swansey, which is much approved by those who are afflicted with some kinds of pulmonary disorders; for it burns like coke, and yields no smoke. It does not soil the fingers, and the chimneys seldom or never want sweeping. In consequence of this, many persons troubled with asthma have taken up their residence in that neighbourhood.

[78] See *Philosophical Transactions*, No. 169.

[79] Kirwan's *Mineralogy*, vol. ii. page 514—528.

There is a very singular kind of coal, as I have been informed, found in some parts of Pembrokeshire, called *stone-coal*. This coal is so devoid of sulphur that it is commonly employed without being previously coked, even in the operation of drying malt, for which purpose either wood charcoal or coke is usually employed. The small of this coal is known by the name of *culm*, and is exported in large quantities from Milford Haven, for the particular purpose above mentioned. The inhabitants of the county where this mineral substance is found, are in the habit of making the culm into balls with clay and water, and laying these up for their winter's consumption. The inhabitants of Pembrokeshire have also a very singular way of using this fuel. When a fire of the large coal has burnt up, a quantity of the culm mixed with clay and water as above mentioned, is plastered over the whole of the fire, of the thickness of three or four inches; and then having made two holes with a poker through this plaster, for the purpose of keeping up a proper draught, it will preserve a good fire, of a perfect glow, without flame or smoke, for 12 or 14 hours.

Hugh Platt in his "Jewel House of Art and Nature," first printed in the year 1594, offers to sell a receipt for making fuel for the poor, which he says will prove more durable and much cheaper than coals. A copy of this work, which is now extremely rare, I had an opportunity of consulting at Chetham's library in the College, Manchester; and

from minutes made in this copy it appears that a Mr. Gosling, merchant of London, disclosed the said method gratis in the year 1628, and was at the expense of printing hand-bills to be distributed in every parish in London and its vicinity, to direct the poor how to make the said fuel. One of these printed hand-bills is attached to the volume above mentioned, from which I have copied the following directions, in the hope of their being useful. "Get," says Mr. Gosling, "a load of stiff loam or clay, and take half a peck of it, and with a shovel make it soft with water, then put one peck of small coal to it, and incorporate or mix them all together until you may roll it or mould it into several parts like pieces of charcoal or long eggs. As many may be made in a day as will last a quarter of a year. Any other combustible may be mixed up with it, such as peat turf, saw dust, curriers' or shoemakers' shreds, tanners' waste bark, and such like." It is added in a note, that "he has dispersed freely many thousands of these hand-bills for the good of all people in the land."

In some districts, coals are raised which have more the appearance of slate or schist than coal, and which only burn in consequence of the bitumen with which they are impregnated. These leave a bulky and stony kind of residuum, and are very unprofitable for most purposes.

There are other pit-coals which are so intimately mixed with sulphuret of iron that they become decomposed by the action of the air, and fall into

dust, or what is called very small slack. Such coals are fit only for heaping upon large fires, for the burning of limestone, or the preparation of coke.

The decomposition of such coal by the accession of water is no doubt the origin of the hydrogen gas, or what is called the coal-damp of many of our collieries, and which often occasions deplorable accidents.

In Lancashire, the workmen get rid of this gas by sending down one of their party to set fire to it, which he does with safety to himself by lying flat upon the ground, and letting it explode over him; but this is a method which could not be practised in some districts with safety.

A method of clearing a coal-pit of the coal-damp, by making a fire and fixing pipes to occasion a circulation, as described by Sir Robert Moray more than a century ago, may be seen in the *Philosophical Transactions*, vol. i. page 79, accompanied with a drawing of the whole of the apparatus.

As coal-pits have been worked in different parts of Europe for almost time immemorial [80], it seems surprising that the proprietors have not long ago investigated the nature of this fire-damp, and devised methods of clearing the mines of it, so as to

[80] According to Wallis, in his *History of Northumberland*, the coal-pits in the north of England were worked when the Romans were in possession of this island. There is good evidence that coal-pits in the neighbourhood of Newcastle were worked as early as the year 1245. Brand's *History of Newcastle*, vol. ii. page 252.

prevent the numerous accidents which we often hear of as happening in these subterranean caverns.

We read that so lately as the year 1763 the nature of this inflammable air of coal-pits was so little known in Dauphiné, that the intendant of the province took measures to discover whether the fire that happened in consequence of it, was not the work of some ill-intentioned persons. The Sieur Finant, surgeon at Briançon, and many others, were so fully possessed with this idea, that, in the prosecution of it, they exposed themselves so as to be grievously scorched and bruised by the action of the inflamed vapour; particularly the Sieur Finant, who was thought likely to be a perpetual cripple, in consequence of his ignorance of this branch of natural philosophy [81]. I hope, however, that the safety-lamp of Sir Humphry Davy will now be the means of lessening the number of these accidents throughout every country where the fire-damp is known. For an account of this important discovery, see pages 127—140 of this volume.

The situations in which coal is found are as various as the composition and properties of the several species of coals themselves. Our deepest mines are in the counties of Durham and Northumberland, and the thickest beds are found in Staffordshire. The most productive vary from 6

[81] *Monthly Review*, vol. xxxvi. page 553, from the *History of the Academy of Sciences at Paris*, for the year 1763.

to 9 feet[82]. In the counties of Gloucester, Worcester, and Stafford; at Newcastle-upon-Tyne; in the neighbourhood of Sunderland; and in many other parts of the kingdom, the coal is raised from very considerable depths; but in the vicinity of Stainthorpe, in the county of Durham, nothing more is necessary than to pare off the turf, and dig out this valuable production at the surface of the ground.

This coal is of excellent quality, much superior to that which is raised in Northumberland for the supply of the London market. If a rail-way were made from Stainthorpe to Stockton-on-Tees, a distance, I believe, of not more than 20 miles, this coal might be conveyed thither at a small expense, and from thence coastwise to London, to the great advantage of the metropolis, and to the enrichment of the district from whence it is to be procured.

A very singular kind of coal is found near the village of Seaton, in the neighbourhood of Hartlepool, in the county of Durham, which is brought up by the tide, and that only occasionally. It is in the form of very coarse sand, the grains of which are so polished that they may be handled freely without soiling the hands, and yet they are so small, that it would be difficult, among a large heap, to find a piece larger than a cherry-stone.

This coal, which abounds with bitumen, and consequently makes excellent fuel, is generally left by the tide on the sea-shore, in a continued ridge, ex-

[82] Brande's *Manual*, vol. iii. page 292.

tending sometimes from a quarter of a mile to a mile in length, three or four inches thick, and only of a few feet in width.

As a considerable time often elapses between the periods when these supplies arrive, a very interesting scene is exhibited whenever one of these strata is thrown up by the tide. In an instant, as it were, all the inhabitants of the village hasten down to the shore, and are seen busily employed in raking it together, and in carting it away before the return of high water, which would wash all that remained off the shore.

Thus, by the bounty of Nature, are the poor of the whole neighbourhood supplied with an article of the first necessity; and merely by a little industry in the summer months are they enabled to lay up an ample store of excellent fuel for the whole of their winter's consumption.

Among the inflammable substances of the mineral kingdom may be classed what is called *elastic bitumen*, or mineral *caoutchouc*, a fusible and very singular substance found in the Odin mine, near Castleton in Derbyshire. It has been fully described by Mr. Hatchett[83], as a compound of carbon, bituminous oil, carburetted hydrogen gas, &c.[84]

Retinasphaltum is another peculiar inflammable body which occurs in the Bovey coal of Devonshire. It is a substance which seems to connect the resins

[83] Scherer's *Journal*, No. 21, page 282.
[84] Klaproth's *Essays*, ii. page 87.

with the bitumens. It was first analysed by Mr. Hatchett[85], and found to consist of 55 resin, 41 asphaltum, 4 earthy matter, &c. = 100.

Mellilite is a rare substance that sometimes is found in the brown coal of Arten in Thuringia, and also in Switzerland. It is of the colour of honey, and from this circumstance was named by Werner honey-stone. It occurs crystallized in octohedrons. Its surface is smooth, it is translucent, and doubly refractive. Its specific gravity is 1.666. According to Klaproth it is a compound of a peculiar acid, which he named the mellitic acid, 46 + alumine 16 + water 38 = 100. By proper evaporation of the solution, the acid may be obtained in crystals. M. Klaproth seems to have analysed the mellilite, and also its acid, with great care[86]. Vauquelin has likewise published a distinct paper on the mellilite, in which he confirms the analysis of Klaproth[87].

It may not be irrelevant to remark, that if a line be drawn upon the map of England across the country from Sunderland to Bristol, all the counties on the west of this line will be found to contain coal[88]. Formerly these counties were the least valuable districts, and the parts of the country which

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[85] Hatchett, *Philosophical Transactions for* 1804.

[86] Klaproth's *Analytical Essays*, vol. ii. page 89—105.

[87] Vauquelin, *Annales de Chimie*, xxxvi. page 203—214.

[88] Coals are also found plentifully in Scotland; but a line drawn on the south of the Tay from the bank opposite to Dundee, along the Ochil hills to Stirling, is esteemed the northern boundary of the coal of this island.

were the most thinly inhabited. Hence, when the constitution of the British Parliament was established, the greatest weight of representation was given to the rich counties which were on the other side of that line [89]. Whereas, now, owing to the establishment of manufactures, the coal-counties have become the most populous and wealthy, and the agricultural districts have either been comparatively deserted, or at least have not much increased in population.

This, in my opinion, accounts in some measure for the inequality of our representation, and shows, very distinctly, the value of our mines of coal, and that by the establishment of manufactures, even the most sterile and forbidding country may be rendered populous, flourishing and opulent [90].

We are, however, much indebted to the wisdom of our Government for our success as a manufacturing nation. It is the true policy of every state desirous of becoming eminent in manufactures, to export none of the native materials which its own people can fabricate, nor to import any thing which

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[89] The 12 English and the 12 Welch counties, lying on the western side of the line we have marked out, send, together, only 114 members to the British Parliament; whereas the 28 eastern counties return 399 members.

[90] The consequences of the establishment of manufactures have been peculiarly striking in some parts of Austrian Flanders. The industry of the inhabitants of Brussels has been such, that an acre of land in the environs of that city will yield in manufactures an amount equal to the revenues of the whole province of *Champaigne*. Carrard *On the Spirit of Legislation*, page 313.

the wants of the state may demand, but in the condition of raw materials; and this for many centuries seems to have been the basis of all our commercial regulations.

In the early periods of our history the woollen manufacture was confined chiefly to the people of Flanders and the Netherlands: but when, in the year 1331, Kempe, a famous Flemish manufacturer, came into this country, that wise prince Edward III. took him under his immediate protection, and published a proclamation, promising the like patronage and favour[91] to all foreign weavers and fullers who would settle in England[92].

The Parliament seconded the patriotic views of that prince, and in the year 1337 made it felony to export wool, whether it was done by foreigners or denizens[93]. Afterwards Henry VI. invited John de Sheidame, a gentleman of Zealand, with sixty persons in his company, to settle in England to instruct his subjects in the new method of making salt, promising them protection and encouragement[94]. This same prince, in the year 1452, invited Michael Gosseleyn, George Hartryke, and Matthew Laweston, three miners, with thirty as-

[91] Many years after this, the same patriotic prince invited John Uninam, William Uninam, and John Lutuyt, of Delft, and granted them his royal protection to exercise their trade of clock-making in any part of his kingdom, without molestation. Rymer's *Fœdera*, vol. vi. page 590.

[92] Rymer's *Fœdera*, vol. iv. page 496.

[93] Ruffhead's *Statutes at Large*, vol. i. page 221. Henry's *History of Great Britain*, 8vo, vol. viii. page 282.

[94] Rymer's *Fœdera*, vol. viii. page 761.

sistants from Germany, to superintend and work the royal mines, and instruct his subjects in their art [95].

In the reign of Queen Elizabeth another Act of Parliament was passed to prevent the exportation of English wool; and the more effectually to secure this source of national wealth, the woolsacks on which our Judges sit in the House of Lords, were placed there to remind them that in their judicial capacity they ought to have a constant eye to the preservation of this staple commodity of the kingdom. From the period we are speaking of to the present times, we all know how alive each succeeding Government has been to the interests of every class of British artists [96], and to this end how successfully they have prevented the introduction of any of the manufactures of France. So early as the 1st of Richard III. an Act was passed to prohibit the importation of the different kinds of cutlery and various utensils in iron and copper, all of which were enumerated in the Act [97]. In the short reign of Henry IV. no less than twelve Acts of Parliament were passed to protect the woollen manufacturers, and prevent the importation of manufactured woollen goods. King Charles I. in the sixth year of his reign issued his royal proclamation, forbidding the clothiers to import iron wire, or cards

[95] Rymer's *Fœdera*, vol. ii. page 317.

[96] England is, I believe, the only country that has ever appropriated any part of its revenues to furnish bounties for the exportation of manufactured goods.

[97] See *Statutes at Large*, 1 Rich. III. cap. 12.

made with foreign wire; and in the fourteenth year of the same reign, another proclamation was issued against the importation of latten or brass wire for the same purpose [98].

But to the patient and unremitting industry of our mechanics, and the frugality of their habits, we are perhaps still more beholden for our success as a manufacturing people [99]. Unlike many of the nations of Europe, who through indolence or inattention suffer the richest treasures of Nature to remain undisturbed in the bowels of their respective countries [100], it has become a custom among us to husband all our resources, and to appropriate every thing, even down to the very residuums of our manufactories, to some useful purpose.

To what degree of excellence our manufacturers and mechanics may arrive in the economy of their materials, when chemical science is better understood by them, and when a knowledge of her laws is more generally diffused, it is impossible to conceive; but this is the point in which we are most deficient, and this is the important desideratum which every person who has any influence in the country should do his utmost to supply.

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[98] Rettus's *Fodinæ Regales*, folio, London, 1670, pages 70 and 71.

[99] I have read of an Emperor of China, who, when he was about to suppress the monasteries of bonzes, declared aloud to the mandarines of the nation, that if he had a man that did not labour, or a woman that did not spin, he was sure some one must suffer cold or hunger in the empire.

[100] There is a remarkable instance of this negligence in that extensive district called the Pays de Vaud, on the lake of Ge-

Notwithstanding our general preeminence in manufactures, it has generally been allowed that in some arts the French very much excell us. For instance, in the arts of dyeing and calico-printing, they surpass us; and Mons. Carrard has declared that it is to chemistry that the French are indebted for the progress which dyeing has made among them; the king's ministers having successively invited the most able chemists to make themselves acquainted with the art, and carefully to examine the principles on which it is founded; and that by their assistance it is, that it has been carried to the highest degree of perfection [101]. Besides which, the Academy of Sciences is constantly engaged in rendering services to the French manufacturers, such as ought to excite our emulation, and rouse our anxiety, not to be outdone in what may be called our own peculiar element. I must not, however, enlarge, and therefore shall conclude with an observation of our own countryman Dr. Home [102] on this subject.

"I consider it," says he, "as a loss to the arts and manufactures of Great Britain, that we have not an academy established by the public authority

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neva. Though the inhabitants of their towns require every luxury that can be procured, neither iron, steel, earthenware, nor glass, is made among them, although they have all the necessary materials in great plenty; and though their wines are abundant, they depend upon foreigners to supply even the vinegar which is required for their home consumption.

[101] Carrard's *Prize Essay on the Spirit of Legislation*, London, 1772, page 332.

[102] Home's *Experiments on Bleaching*. Edinburgh, 8vo, 1756.

and expense, for attending to their progress. The members of this academy, having an honest necessity of pursuing their genius, might without any inconvenience give ear to the voice of fame. It has cost very little to France for her Academy of Sciences; and yet what advantages has it procured to the arts and manufactures of that country! It is to this that the French owe their superiority in many of the arts. In establishing this academy, Louis XIV. triumphed over those whom he could not vanquish by his arms."

ESSAY VII.

ON

SULPHURIC ACID.

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WHEN sulphur mixed with a certain portion of nitre is burnt over water, in a closed vessel containing atmospheric air, a peculiar acid is formed during the combustion, which is known to chemists by the name of SULPHURIC ACID.

This acid is formed in many of the operations of nature[1], but we have no reason to believe that the ancients knew this, although they were well acquainted with its base, sulphur[2], which they sometimes employed with other combustible substances in religious oblations. So early as in the first century sulphur was employed in bleaching woollen cloth, and for other purposes, as may be seen in the second volume in the Essay on Bleaching.

[1] Disengaged sulphuric acid has occasionally been found native in some parts of Italy; *Journal de Phys.* tom. vii. page 395.

[2] Pliny, lib. xxxv. cap. 15.

Vitriol, or sulphate of iron, is mentioned by Pliny in his Natural History; but it does not appear that he knew any thing of its chemical composition.

Aulus Gellius relates that Archelaus, one of the generals of Mithridates, washed over a wooden tower with a solution of alum, and by this project rendered it so much proof against fire, that all the attempts of Sylla to set it in flames proved abortive[3]. There is, however, no question but that this was *sulphate of iron* which was applied, for it has been proved that the ancients gave this salt the name of alum[4].

The first mention of sulphuric acid occurs in the writings of Basil Valentine, a celebrated chemist of Erfurt. In his time, however, the quantity produced must have been small, and its consumption

[3] Æneas recommended vinegar to be washed over wood to prevent its being destroyed by fire. The opinions of the Duke of Rochefoucault, Lavoisier, Cadet, and Fourcroy, on the substances proper to be used for the prevention of fires, may be found at the conclusion of a memoir on a ridiculous experiment related in the *Annales de Chimie*, tome v. page 141.—See also the *Stockholm Memoirs* for 1740, and a memoir by M. Fougeroux, published in the *Mém. de l'Académie Royale à Paris, année* 1766. An account of a liquor, for dressing wood to preserve it from fire, which was prepared from sulphate of iron, &c., and bought with great avidity in Sweden, may be read in Crell's *Annals of Chemistry* for the year 1793. An account of a natural bed of martial pyrites, from which the inhabitants of that part of Russia in which it is found make copperas (sulphate of iron), may be seen in Tooke's *View of the Russian Empire*, vol. i. page 86. There is a sulphate of iron collected in the island of Ceylon, which is a crystallized pyrites containing a little copper, and with which the inhabitants manufacture very durable buttons.—Cordiner's *Description of the Island of Ceylon*, quarto, 1807, vol. i. page 13.

[4] Beckmann's *History of Inventions*, vol. i. page 294.

very circumscribed. It was also known to Paracelsus, the Swiss alchemist, who died so early as the year 1541; and it is evidently referred to likewise in a work entitled *De Re Metallica*, which was published by George Agricola, a German physician, in the year 1542; but I know of no proper characteristic description of this acid by any of the writers of that period. The first person who gave any thing like a correct account of sulphuric acid was Gerard Dornæus, in a work which he published in the year 1570; and again in another edition of the same work, which he republished at Frankfort in the year 1581.[5]

When sulphuric acid was first prepared by art, it was distilled from dried sulphate of iron, the common *green-vitriol* of commerce. Hence, when the component parts neither of the salt nor of the acid were known, it was very naturally called *oil* of vitriol. Or it might have acquired the name of *oil* of vitriol from the circumstances of its resemblance to oil in adhering to the sides of a vessel containing it, and in its occasioning little noise when poured from one vessel to another.

This name should now be expunged, as it tends to give false ideas of the nature of the acid, and may mislead and bewilder a young chemist. Oil does not mix with water, but sulphuric acid does in all proportions; oil is composed of hydrogen

[5] This work is entitled "Congeries Paracelsicæ Chemiæ de Transmutationibus Metallorum, ex omnibus quæ de his ab ipso scripta reperire licuit hactenus; access. Genealogia Mineralium atque Metallorum omnium." 8vo. Francf. Wechel. 1581.

and carbon; but neither of these substances enters into the composition of sulphuric acid, which has been demonstrated by analysis, as well as synthesis, to be formed only of sulphur, oxygen, and water.

Sulphate of iron is prepared from martial pyrites, which is a native sulphuret of iron. It is found in abundance on the island of Sheppy and elsewhere. By exposing this to the air in large beds, oxygen is absorbed, the sulphur becomes sulphuric acid, and the newly formed salt is separated by washing.

All the sulphuric acid which is prepared in Saxony, and in many other parts of Germany, is still procured from sulphate of iron. In the *Journal de Physique* there is a very particular account, by Mr. Fragoso, of the distillation of this acid from copperas, as it is now practised at Bleyl, a village in Bohemia[6]. To conduct the operation in the best manner, seven or eight days will be required, and during two-thirds of this time the fire must be kept at the highest pitch. Bernhardt, who was well acquainted with this process, tells us that he procured only 64 pounds of sulphuric acid from six hundred weight of sulphate of iron. Directions for conducting the operation have also been given by Glauber; but according to him, a much purer sulphuric acid may be obtained from sulphate of zinc, and with less labour[7].

At one time the English makers of sulphuric

[6] An abridgement of this account may be seen in the thirteenth volume of the *Repertory of Arts*, page 269.

[7] The Works of John Rudolph Glauber, folio, London, 1689, page 17

acid distilled the green vitriol in earthen vessels called long-necks, placed within a reverberatory furnace with a glass receiver luted to each retort. It was usual to put fifty or more of these into one furnace [8].

The makers of sulphuric acid having found great inconvenience in procuring it from sulphate of iron, on account of the length of time which was necessary for the operation, the small quantity of acid that was procured by this means, and the intense heat required for its distillation, which always destroyed the stills with great rapidity, and entailed upon them a perpetual and enormous expense, had at length recourse to the base itself, to the sulphur, which, in conjunction with nitre, was burnt in very large globes of glass, and the product was concentrated by boiling it in retorts or other glass vessels, until the fluid was of a sufficient strength for sale.

It may be proper, however, before we proceed with the account of the manufacture of sulphuric acid, to say a word or two respecting the sulphur.

Sulphur, or brimstone, as it has usually been called, is a simple combustible substance, quite undecomposable, at least by any of our present methods of analysis, and it differs in its nature and properties from all other known bodies. It is chiefly procured in the neighbourhood of volcanoes, and also from some of the native sulphurets; but

[8] Dr. Lewis's Edition of *Neumann*, vol. i. page 277.

what is used in this country is usually imported from Sicily. Its chief consumption is in the manufacture of sulphuric acid; though it should be recollected, that if sulphur be burnt slowly, and without any admixture, *sulphurous*[9] and not sulphuric acid will be formed.

Sulphur burns very differently in different circumstances; Stahl found that an ounce of sulphur, burnt with a wick, may be made to yield a constant flame for six hours; and that, when the wick was very small, only 15 or 16 grains were consumed in an hour[10]. When sulphur is heated to about 190°, combustion begins, and a pale blueish flame is emitted with the production of a very small degree of heat. The heat thus generated is so inconsiderable that Baumé contrived to burn off the whole of the sulphur from a quantity of gunpowder without exploding the powder[11].

I have seen no account of the preparation of sulphur in any of the modern systems of chemistry. A few particulars relating to the process appeared in an early volume of the *Philosophical Transactions*, which I shall insert, believing they will be acceptable to the reader.

"The mineral out of which brimstone is extracted

[9] An elaborate account of a series of experiments on the nature and habitudes of this acid was published by Berthollet, in the *Memoirs of the Royal Academy* for 1782. A continuation was afterwards given to the Academy, and published in the *Annales de Chimie*, tome ii. page 54—72. Observations of Chaptal on some phenomena accompanying the combustion of sulphur appear in the same volume, page 86.

at Liege is not much unlike lead-ore, having also oft-times much lead mingled with it, which is separated from it by picking. To make brimstone, they break the ore into small pieces, which they put into crucibles made of earth, five feet long, square and pyramid-wise. The entry is near a foot square. These crucibles are laid sloping, eight undermost, and seven above them, as it were betwixt them, that the fire may come at them all, each having its particular furnace or oven. The brimstone being dissolved by the violence of the heat, drops out at the small end of the crucible, and falls into a leaden trough or receiver common to all the said crucibles, through which there runs a continual rivulet of cold water, conveyed thither by pipes for the cooling of the dissolved sulphur, which is ordinarily four hours in melting [12]." From the ashes left in the crucibles they afterwards make crystallized sulphate of iron [13].

Sulphur is a hard and brittle substance of a yellow colour, which very much varies in its intensity; it has neither taste nor smell unless it be heated. When melted in a large mass, it crystallizes on cooling. Such crystals as are transparent, are in a high degree doubly refractive; and its specific gra-

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[10] Lewis's *Neumann*, vol. i. page 255.
[11] Macquer's *Dictionary*, article *Sulphur*.
[12] *Philosophical Transactions for the year* 1665, page 45.
[13] The method of extracting sulphur at Goslar may be seen in Dr. Lewis's Edition of *Neumann*, vol. page i. 264.

vity, when tolerably pure, is about 1.990. It has the property of becoming negatively electrical by heat and by friction. It liquefies at the heat of 225°, and this liquid becomes thicker and thicker as the heat is increased; and when it has acquired the heat of 560° or 600°, it begins to sublime, and the article known in commerce by the name of *flowers of sulphur* is produced. Roll sulphur is generally procured from British sulphuret of copper: this is at first separated from the mineral by sublimation, and then the sublimed sulphur is remelted and purified before it be cast into sticks for sale. When sulphur is pure, it will evaporate entirely, and leave no residuum. Its purity may also be judged of by dissolving a portion in boiling oil of turpentine; for if pure, every particle will be dissolved by the action of that menstruum. The equivalent number for sulphur is 15.

It is generally understood that the sulphur which is imported varies very much in its quality, and this is confirmed by the different accounts we have of its specific gravity:

Sp. Gr.	Sulphur according to Roger Cotes is .	1.8000
	Common Brimstone.—John Caswall .	1.8110
	————————.—John Freind .	1.8750
	Very fine German.—Boyle	1.9800
	Common.—Dr. Thomson	1.9900
	————.—Dr. Henry	1.9907
	Transparent Persian.—Richard Davis .	1.9500
	Sulphur Vivum.— ———————— .	2.0000
	Roll Sulphur.—Hauksbee	2.0100
	————————.—Petitus	2.3440

The process of forming sulphuric acid by the combustion of sulphur is so very different from the original method of procuring it by the simple distillation of sulphate of iron, and has occasioned such important changes in a variety of the manufactures of the country, that I have considered it to be right to take some pains to trace the progress of the new method; especially as it will in a few years be difficult to acquire any correct information on the subject; and as I had formerly some connexion with the family of one of the principal original manufacturers, I obtained the possession of some facts which I am desirous of communicating to the public. Moreover, the gratification which arises from being the means of recording the origin of a manufactory of so much importance, and a discovery so much to the honour of the British empire as the process for producing this acid in an economical way, will, I trust, be my excuse for allowing the following detail to occupy so much room in this Essay: for when the state of chemical science at the date of the invention is considered, one can scarcely hesitate to pronounce this to be one of the greatest efforts of human genius; as neither the nature of nitre, nor of the process of combustion, was at that time at all understood.

The method of forming sulphuric acid by the combustion of sulphur was first adopted in this country by Dr. Ward, the vender of a noted analeptic pill, and the inventor of the *white drop*, and

some other celebrated nostrums which bear his name. It has generally been said that Dr. Ward was the author of this important discovery; but Fourcroy attributes it to two French chemists, Lefevre and Lemery. The works of the latter I have consulted, and in an edition printed more than a century ago, I find an express process for producing sulphuric acid by the combustion of sulphur and nitre; though it is probable that before Dr. Ward's time the quantity made in this way was very inconsiderable; for Lemery tells us that he prefers the acid made without nitre [14]. An exclusive right to this mode of making sulphuric acid in Great Britain was, however, granted to the Doctor by patent; and, by way of distinction, the article which he prepared was called "Oil of vitriol made by the bell," and was sold from 18*d.* to 2*s.* 6*d.* per pound.

The glass vessels which were employed for this process were made with wide necks, and as large as they could be blown with safety, and capable of holding forty or fifty gallons. These were placed in two rows on a bed of sand, and at a sufficient distance from each other to be conveniently approached. A few pounds of water being poured into each glass, a stone-ware pot was introduced into the neck, and on this was placed an iron ladle previously made red-hot. Into this last, by means of another ladle of tin-ware, a mixture of sulphur

[14] Fourcroy's *System of Chemical Knowledge*, London, 1804, vol. ii. page 83. Lemery's *Chemistry*, London, 1698, page 448.

and nitre was put, and then the aperture of the glass vessel was immediately closed with a stopper of wood. The heat of the iron ladle set the sulphur and nitre on fire; and when the combustion was finished, the iron ladle was taken out, and the vapours suffered to condense.

The same operation was successively conducted in each of the glass vessels composing the two rows; so that the workman, after passing through the whole range, arrived at the first vessel at the time when the vapours were totally condensed, and the vessel consequently in a state to receive a new portion of the matter [15] for burning.

The British manufacture of this acid was thus monopolized by Dr. Ward for a considerable time: but when the term of his patent expired, several other persons became engaged in the business, and conducted it after an improved method. Mr. Dossie has given a very particular description of his method, and of the glass globes and other apparatus which were employed in his time for the purpose; from the perusal of which the nature of the manufacture will be thoroughly understood [16]. At length, however, chambers of lead were employed for the combustion of the sulphur and nitre, which were so contrived that the floor of each

[15] About the same time, or soon after Dr. Ward commenced this process in England, a similar plan was adopted in Holland to a large extent. See Thomson's *Edition of Fourcroy*, vol. ii. page 158.

[16] Dossie's *Elaboratory laid open*, Oct. 1758, Introduction, page 44.

might be constantly covered with a sheet of water, capable of absorbing the sulphuric acid gas at the time of its formation.

The introduction of the leaden apparatus is a memorable event in the history of the progress of this manufacture, as it has laid the foundation of its present magnitude, and in a very short time reduced the price to about one quarter of its former rate.

The credit of this very important improvement belongs to the late Dr. Roebuck, an eminent physician of Birmingham, who, in conjunction with his partner, the late Mr. Samuel Garbett, erected the first leaden chamber for this purpose, at Birmingham, about the year 1746. These gentlemen were violently opposed by Dr. Ward, who considered their manufactory to be an invasion of his patent; they succeeded, however, in completely establishing it, and the same works are now in the occupation of their successors, Messieurs Alston and Armitage.

Owing to the interior situation of these works, and the great expense and risk of land carriage, there being at that time no conveyance by canals, the consumption was almost entirely confined to that town and neighbourhood. A considerable portion of the acid was employed in the distillation of nitrous acid, which is in great demand there for the use of the various manufactories. Much of it was also used as a solvent for copper, for the double

purpose of making Roman-vitriol, and of recovering the gold and silver from waste gilt and plated metal.

These manufacturers, however, were not long satisfied with this confined consumption: in order therefore to create a more extensive demand, and likewise with a view to the introduction of it for the purpose of bleaching in the linen manufactories of Scotland and Ireland, in the year 1749 they established works at Prestonpans on the eastern coast of Scotland on a very extensive scale.

That nothing might be neglected which was likely to promote this object, Dr. Home, then professor of chemistry in the university of Edinburgh, entered upon a course of experiments to ascertain the powerful effects of sulphuric acid, when properly employed, in whitening linen cloth without prejudice to the fabric. These experiments were afterwards published, together with directions as to the mode in which the new agent ought to be employed. This, by degrees, had the desired effect, and finally exploded the use of sour milk, which till then was the only acidulous article that had ever been used in bleaching.

Dr. Roebuck, whose memory is still held in great esteem at Birmingham, was a man of very superior talent, of the most amiable manners, and very considerable acquirements. Indeed, the peculiar intimacy which long subsisted between Dr. Roebuck and the illustrious Dr. Black, is of itself alone sufficient to show that the former must have been a

man of superior endowments. Dr. Robison, in his preface to Black's *Lectures*, 4to, page 69, speaks of his intimacy in very respectful terms. Dr. Roebuck cannot, however, properly be said to have been the *sole* founder of the works at Prestonpans, or of the great iron works at Carron, as is asserted by a writer in one of the *Encyclopedias*; for in the former of these he was connected from the very first with Mr. Garbett, who, as a merchant, was also a man of highly distinguished abilities. Of the latter, the Doctor and his three brothers, together with Mr. Garbett, and Messieurs Cadell and Sons, of Cockenzie near Prestonpans, were the original projectors and founders, (I mean of the vast work at Carron,) to the great prejudice of their respective fortunes, from the immense outlay of money required to carry their plan into execution. This, with an unfortunate concern in a colliery at Borrowstoness, brought ruin on all the Doctor's fair prospects in life [17].

In reverting to the manufacture of sulphuric acid, it ought to be noticed that for several years Messieurs Roebuck and Garbett carried on their works in England and Scotland with great success and without any opposition. They not only supplied the demands of Great Britain and Ireland, but exported very large quantities of sulphuric acid to the continent of Europe.

These establishments had continued to increase,

[17] This excellent man died on the 17th of July 1794.

and were become of very considerable importance, when an untoward accident gave rise to an opposition which spread the first cloud over their future prospects.

It was about the year 1756, when one of their workmen at Birmingham, who was a hired servant, absconded from their service, and his misdemeanours and refractory conduct rendered it inexpedient to attempt to reclaim him. This man being a native of Bridgenorth, he went thither, and had the art to induce a Mr. Rhodes [18], an eminent seed-crusher, and proprietor of large oil-mills in that town, to embark in the business.

A small work was accordingly set up at Bridgenorth, on the banks of the Severn, and there the manufacture was carried on for many years. This man did not, however, continue long with Mr. Rhodes; but engaged himself to Mr. Skey of Bewdley, who had just begun a manufactory of sulphuric acid on a scale much larger than that at Bridgenorth.

This establishment was also on the banks of the Severn, at a place called Dowles, near the town of Bewdley, in the county of Worcester, and was the third English work for manufacturing this valuable commodity by the combustion of sulphur in leaden chambers.

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[18] The late Miss Rhodes of Bridgenorth, a woman of fine taste and considerable acquirements, was the daughter of this gentleman. She was the author of several papers in the *Transactions of the Society for the Promotion of Arts, Manufactures, and Commerce*, on the manufacture of silk in Great Britain, and for which the silver medal of the Society was awarded her.

At first these chambers were only six feet square; but Mr. Skey erected his ten feet square, and in vessels of that size he continued the manufacture for many years.

These chambers were erected under the direction of a man who had formerly worked at Preston-pans, and who having been discharged from thence, was travelling through the country with his family in search of employment.

Mr. Skey, who was a man of great enterprise, having by accident seen this individual and heard his account of the nature of the business, at once determined that he would engage in it, and manufacture the article on as large a scale as its demand should require.

Such was the origin of the extensive manufactory at Bewdley; and as the materials at that time were cheap, and the acid was sold dear, this establishment was the means of raising its founder to a state of great opulence. At his decease, the whole of the chemical works were carried on by his son the late Samuel Skey, Esq., and since his death they have been continued, and are still in full work, for the benefit of his children.

Considering the nature and importance of Dr. Roebuck's improvement, it is a remarkable circumstance that similar establishments were not sooner formed in various parts of the kingdom; and that twenty-five years should have elapsed before any spirited individual in the metropolis, or in its vicinity, had availed himself of the advantages of the invention.

According to the best information which I have been enabled to obtain, Messieurs Kingscote and Walker, druggists of London, were the first persons, south of Birmingham, who attempted to make sulphuric acid in vessels of lead. Their manufactory was established in the year 1772, at Battersea, four miles from London, and on the 24th day of December 1771 the first barge-load of lead was navigated on the Thames up to Battersea for the construction of the chambers.

This establishment consisted of seventy-one circular leaden vessels, each six feet in diameter and six feet in height, constructed in the following manner:—A sheet of lead was folded round a wooden cylinder prepared for the purpose, and upon this immense maundrel the vessels were formed into shape, and then the edges of the sheets were lapped together and soldered. Each vessel was afterwards reared on one end upon a bottom of lead, and when thus fixed, it was covered with a dome of lead firmly soldered upon it.

These receptacles had each one aperture, which, during the time of the combustion of the sulphur, was closed by a door of mahogany nicely adapted to it: besides which, each vessel had an outer door of the same species of wood to be shut before the former, in order to close the opening the more effectually. These rooms stood in five separate rows, independently of each other, and all were inclosed in one large brick building, to preserve them from the effects of the sun and wind.

Besides the apparatus which I have described, these manufacturers erected also several square houses of lead, which were perfect cubes of twelve feet each; and these, together with the former, were regularly employed for many years. I have been the more particular in describing this work, as I conceive it to have been the most curious and expensive establishment that was ever formed in these kingdoms for a similar purpose.

Several unfortunate circumstances, not worth relating at this period, conspired to render this manufactory unproductive of profit; in consequence of which it was at length broken up, the vessels were taken down, and every thing was sold by auction under the description of old materials.

Soon after the destruction of this manufactory, Mr. Walker, a nephew of one of the late partners at Battersea, connected himself with two other gentlemen, and they, under the firm of Baker, Walker, and Singleton, some time about the year 1783 established a sulphuric acid manufactory of very considerable extent, at Pitsworth-Moor near Eccles in the county of Lancaster. This manufactory, which was the first establishment of the kind in that county, consisted of four vessels each twelve feet square, and four others, each of which was forty-five feet long and ten feet wide.

Not long after the formation of this manufactory, another work was established at Leeds; and by degrees they have spread into many different parts of England and Scotland, as well as Ireland; and, not

to particularize other places, there are now no less than eight considerable and distinct manufactories of sulphuric acid established at Birmingham and in its immediate vicinity.

When the formation of sulphuric acid by combustion in leaden chambers was completely established by Dr. Roebuck, little or no improvement was made in the manufacture for many years. However, in the year 1788, a memorable era in the history of the trade of this country, when the new method of bleaching by oxymuriatic acid was introduced, the sale of sulphuric acid was much increased, especially in some particular districts. From this time the demand became enormous, and almost unlimited in extent; so that, from this single and unexpected circumstance, the manufacturers of this acid found it necessary to erect chambers of much larger extent for the combustion of the sulphur; and these have been enlarged again and again by the great makers, so that now a common rate manufactory for sulphuric acid is really an establishment of serious concern, in respect to capital and magnitude.

The size of the leaden chambers in modern use, is from 20 feet long and 12 wide to 40 or 60 feet long and 16 or 18 feet wide [19]. One manufacturer,

[19] Count Chaptal, who was formerly a considerable manufacturer of sulphuric acid, says, "Those chambers which are about twenty feet broad by twenty-five long and fifteen high, seem to me to be of the most advantageous proportions." *Chemistry applied to the Arts*, vol. iii. page 40.

however, in Lancashire has several leaden chambers of the enormous dimensions of 120 by 40 feet, and 20 feet high, consequently forming a space of 96,000 cubic feet each. It is impossible, indeed, to say to what extent the enlargement of these vessels may not be carried by the opulent manufacturers, who seem to set no bounds to their expenditure, especially as we are at present in possession of no facts by which it is possible to determine which is the best form, or what is the best size of a House[90] for the manufacture of sulphuric acid.

The process, however, whatever may be the size of the chambers, is generally conducted in the following manner:—A quantity of common brimstone, coarsely ground, is carefully mixed with crude saltpetre in the proportion of seven or eight pounds of the former to one pound of the latter; and this mixture is afterwards divided into separate charges, containing quantities proportioned to the size of the chamber in which they are intended to be burnt.

I never heard of *refined* nitre being used for this purpose; and yet many of the manufacturers of sulphuric acid instruct their brokers to purchase only such lots for them, at the sales of the East India Company, as have a small refraction, as it is termed, and are consequently esteemed to be of superior quality.

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[90] House is a technical name for these leaden chambers. In some districts they are called leaden vessels.

The best method for apportioning the mixture of sulphur and nitre to the size of the house, appears to me to be this: to allow one pound for every 300 cubical feet of atmospheric air contained within the chamber; that is, if a house be an oblong square of 40 feet by 15 feet, and 15 feet high, the contents in cubic feet will be 9,000, and such a chamber will take 30 pounds of the mixture at each charge.

The mixture of sulphur and nitre is usually spread upon several plates either of iron or of lead; and these are afterwards placed upon stands of lead within the chamber, at some distance from each other, and a foot or two above the surface of the water. Things being thus arranged, the sulphur is lighted by means of a hot iron, and the doors are then closed.

If well mixed, the brimstone and nitre will soon be in rapid combustion, which will continue for 30 or 40 minutes, during which time the chamber will become entirely filled with gas.

Three hours, calculating from the time of lighting, are generally allowed for the condensation of this gas; and then it is customary to throw open the doors for a quarter of an hour or half an hour, for the free admission of atmospheric air and the expulsion of all the incondensable gas, in order that the house may be thoroughly sweetened, as it is called, for the next burning.

During this interval the plates are again charged, and preparation is made for a fresh combustion,

which is thus repeated every four hours, day and night, without intermission, until the water at the bottom of the chamber is thought to be sufficiently acidified, when it is drawn off, by means of a syphon, into a reservoir of lead, conveniently placed for its reception, and the floor of the chamber replenished with water for another operation.

Some manufacturers make it a rule to remove the acid out of the chamber when it begins to turn black; and this, I think, generally happens when it is of a specific gravity between that of 1,350 and 1,450; though I suspect that most of the makers suffer it to remain until it acquire a specific gravity of at least 1,560.

Whatever number of leaden chambers a manufactory may consist of, it is customary to work them all in this way, day and night, without interruption: for, as it requires a large sum in the first instance to form a sulphuric acid establishment, the operation being tedious, the return slow, and the product very small compared with the capital, the interest of money must be a heavy charge on the trade; and this is a constant spur to the manufacturer, making him anxious to get as large a produce as possible from each chamber.

When the acid has been drawn from the house, it is pumped from the reservoir into a large leaden boiler, which is usually an oblong square, and there it is heated till a copious vapour arises from its surface, when the operator ceases to increase the fire; still, however, keeping the liquor steaming day and

night, until it has acquired that exact specific gravity, at which he considers it to be most economical to stay the process.

Where a proper attention is paid to the saving of labour, another reservoir is provided, which is placed contiguous to the boiler, and into this the concentrated acid is syphoned, where it is preserved, closely covered from the action of the atmosphere, until it is convenient to remove it to the rectifying house. There it is boiled in retorts of glass, until the remainder of the sulphurous and nitrous gas is driven off, and the acid has acquired the usual concentration for sale.

To explain why these different operations are necessary for procuring sulphuric acid in its highest state of concentration, it may be remarked, that whenever the acid in the leaden chambers has acquired a certain specific gravity, it will refuse to absorb the gas with the same avidity as at first; therefore, in order to conduct the process economically, the acid liquor must at that time be removed, and water poured in to supply its place.

It is equally necessary, when in the leaden boiler, to draw it off before it becomes too much concentrated; because the boiling point of sulphuric acid always increases with the increase of its specific gravity; and its boiling point is so very near to that at which lead melts [21], that there would be great

[21] Lead melts at 612° of Fahrenheit; and Mr. Dalton states that the concentrated sulphuric acid of commerce of the specific

danger of the metal giving way, were an attempt made to concentrate the acid beyond a certain point in such utensils; to say nothing of the loss of that portion of acid which would be decomposed by the metal, and of the impurity which the remaining acid would acquire from the large quantity of lead that would then be dissolved.

From some late experiments which I have made on the fusibility of various compounds of lead and tin, I have been convinced that in the fabrication of leaden boilers the utmost attention ought to be paid to the *purity* of the metal, and care taken that no lead be used but such as is free from every alloy.

Having occasion a few years ago to purchase several tons of sheet-lead for the construction of an oil-of-vitriol chamber and other chemical apparatus, I accidentally discovered that there is often a great deal of sheet-lead in the market which has been manufactured from *old* lead, which usually contains some solder and other impurities. In the construction of steam boilers for the concentration of sulphuric acid, such lead ought to be carefully avoided; for a small portion of tin or plumber's solder, which is usually found in old lead, will when mixed with pure pig-lead reduce the melting point of the whole of the metal very considerably, as may be seen in the *Tables*, which I constructed in the year 1815,

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gravity of 1,848 boils at 590°; but that if the specific gravity amount to 1,849, it will require a heat of 650° to bring it to the state of ebullition.

of the melting points of various metallic compounds, and which will be given in the second volume.

Some manufacturers are, indeed, so curious in the quality of the article, that they never steam it in lead at all, but remove it at once from the chamber of combustion to the retorts of glass. This is, doubtless, the best way of conducting the business; because acid thus prepared can contain but a very minute portion of lead, it having no opportunity of acting very powerfully upon that metal [22].

Having thus given but a brief account of the nature of this manufacture, it will be necessary to add a few words upon the properties of the acid which is the subject of this Essay.

I have already noticed that sulphuric acid is a compound of sulphur, oxygen, and water; but it must be observed, that sulphur is capable of forming with oxygen two distinct compounds, containing different proportions of oxygen, and possessing very different properties. Thus, if sulphur be burnt in oxygen gas over water, the water will absorb the sulphurous gas which proceeds from the combustion, and be converted to *sulphurous* acid; but if

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[22] The sulphuric acid of commerce always contains a portion of lead, and sometimes a small quantity of the sulphate of potash. Whenever sulphuric acid is required to be perfectly pure for chemical experiments, or medicinal purposes, distilled water might be added to some of the common acid of the shops, until these impurities were all precipitated; and, if necessary, the water might then be abstracted by evaporation in a glass vessel.

a certain proportion of nitrate of potash be mixed with the sulphur before it be ignited, the product of the combustion will be *sulphuric* acid.

Sulphurous acid gas is composed of 1 proportional of sulphur=15 and 2 of oxygen=15; so that its equivalent number must be represented by 30.

Sulphuric acid is composed of 1 proportional of sulphur=15, and 3 of oxygen=22.5; so that the number representing *dry* sulphuric acid, or sulphuric acid in the state in which it is found in the native sulphuric salts, and in several artificial compounds, will be 37.5.

The strongest *liquid* sulphuric acid is composed of

1	proportional	of sulphur	= 15
3	ditto	of oxygen	= 22.5
1	ditto	of water	= 8.5
			46

Thus 46 becomes the number for liquid sulphuric acid: and, according to Dr. Ure's Table lately published, if 54 parts of water be added to the 46 parts of this concentrated acid, the 100 parts of diluted acid will be of the specific gravity of 1.3530.

It must, however, be recollected, that though these are the real proportions of sulphuric acid, no method has yet been discovered of making that quantity of acid from a given weight of the sulphur which these proportions indicate.

It is remarkable, that when sulphur is burnt in dry oxygen gas, the sulphur combines with the gas

without increasing its volume. One hundred cubic inches of oxygen weigh 33.75 grains, and this volume of oxygen is capable of combining with 33.75 grains of sulphur; from whence it follows, that 100 cubic inches of sulphurous acid gas must weigh 67.5 grains, and this by experiment is found to agree exactly with the theory. The composition of sulphurous and sulphuric acids is therefore put beyond all doubt.

It was usually imagined that the formation of sulphuric acid is brought about by the union of the oxygen of the nitre with the sulphurous acid; but it was soon found by calculation that the nitre usually burnt with the sulphur is not adequate to the supply of one-thirtieth of the oxygen that is required for the conversion of sulphurous to sulphuric acid; and the matter remained unexplained for a considerable time, till Messrs. Desormes and Clement, two eminent manufacturers of sulphuric acid at Paris, presented in the year 1806 a memoir on the subject to the French National Institute[23]; in which they gave the following satisfactory elucidation of the mode in which the nitre acts so as to promote the formation of sulphuric acid.

The sulphur, say they, when burnt in atmospheric air, forms sulphurous acid; but if the sulphur be previously mixed with nitre, the nitre furnishes *nitric oxide*, and this, by uniting with the oxygen of the air within the chamber, is converted to *nitrous*

[23] *Annales de Chimie*, vol. lix. pages 329—339.

acid gas; and that the latter, when it comes in contact with the sulphurous acid, parts with a portion of its oxygen, and that this converts the *sulphurous gas* to *sulphuric acid gas*. By this process the nitrous acid gas becomes reconverted to nitric oxide, and this detaches more oxygen from the atmospheric air, and conveys it to the sulphurous acid as before. The nitric oxide thus acts as a carrier between the atmosphere and the sulphurous acid; it transports the oxygen from the atmospheric air to the sulphurous acid, and leaving these in union, it performs the same office again and again, until the whole is oxidized. To prove the truth of this theory, Mr. Dalton contrived the following beautiful and satisfactory experiment[24]:

"Let 100 measures of sulphurous acid gas be put into a dry tube over mercury, to which add 60 of oxygen gas; let then 10 or 20 measures of nitrous gas (nitric oxide) be added to the mixture; in a few seconds the inside of the tube becomes covered with a crystalline appearance, like hoar-frost, and the mixture is reduced to one-third or one-fourth of its original volume. If now a drop of water be admitted, the crystalline matter is quickly dissolved in the water, sparkling as it enters, and the gases entirely lose their elasticity, except a small residuum of azote and nitrous gas. If the tube be then washed out, the water tastes strongly acid, but has no smell of sulphurous acid.

[24] *New System of Chemical Philosophy*, page 396.

It is evident, that in this process the nitrous gas unites to the oxygen, and transports it to the sulphurous acid, which, receiving it from the nitrous gas, becomes sulphuric acid. It appears, moreover, that solid sulphuric acid is formed when no water is present; and consequently this is the natural state of sulphuric acid entirely free from water."

Sir Humphry Davy, however, discovered that nitric oxide has no action whatever on sulphurous gas, unless moisture be present, but that with a very small proportion of water they form a white crystalline matter, which is instantly decomposed by the addition of more water, with the extrication of nitric oxide; and this by the contact of atmospheric air, or oxygen, becomes nitrous acid as before. Sir H. Davy proves this necessity for water, by a very beautiful experiment, which he was good enough to show to me several years ago, and which must be perfectly satisfactory to every one who witnesses it.

When sulphuric acid is pure, it is entirely devoid of colour and smell; it is extremely acid and corrosive, and one of the most ponderous fluids we are acquainted with. It is capable of uniting with the earths, the alkalies, and most of the metallic oxides, and in these combinations it forms those salts which are known by the name of sulphates.

Having said that sulphuric acid is corrosive, I am desirous, before I proceed to mention its other properties, of observing that instances may occur of its being taken into the stomach by mistake, and without immediate relief its corrosive properties would

produce fatal effects. If magnesia should be at hand, that earth mixed with water and sweetened with sugar, would be the best possible antidote to the poison; but in case this could not be immediately procured, soap-water, which can be furnished by all families, and which is one of the next best remedies, should be drunk plentifully. The unfortunate death of an infant son of the Hon. and Rev. E. Knox, at Dungarvon Park, in consequence of his swallowing a quantity of oil of vitriol which had been carelessly left on the table by a female domestic, shows how important it is for the public to be acquainted with the proper remedy in such cases.

The most distinguishing characteristics of sulphuric acid are, its peculiar affinity for barytes, which it is capable of separating from all other combinations; and its attraction for water, which it absorbs with great avidity, even from the atmosphere, whenever it is exposed to it in a state of concentration. The attraction which sulphuric acid has for water is so powerful, that in certain operations of the laboratory it is often employed for the purpose of creating a dry atmosphere.

The great affinity of sulphuric acid for water may be shown by the following very easy experiment:— If the bulb of a thermometer be dipped in concentrated sulphuric acid, it will probably not be perceived that the immersion has occasioned any alteration in the temperature of the thermometer; but if it be withdrawn and held in the open air, the small portion of acid which adheres to the bulb will

absorb water from the atmosphere with so much rapidity (especially if it be in damp weather) that in a few seconds the mercury in the thermometer will be seen to rise several degrees.

The mixture of sulphuric acid and water occasions a great extrication of caloric. If a thermometer be placed in a glass of water, and concentrated sulphuric acid gradually added, the mercury will instantly begin to ascend, and progressively to a certain extent; and if two pounds of this acid be suddenly mixed with one pound of water, the temperature will immediately be raised much higher than that of boiling water [25]. No advantage seems, however, to have been taken of this property of sulphuric acid, though it affords the means of furnishing a variety of degrees of heat in an instant. Indeed, the rapidity with which the temperature becomes afterwards reduced, would probably be an obstacle to its employment in any of the operations of the laboratory, or in the affairs of common life. I have, however, as a matter of curiosity, constructed the following table of the different temperatures which are produced by the mixture of water in various proportions with this acid.

The temperatures of the water which I employed, and of the atmosphere of the room were both at 50°. The acid was the common oil of vitriol of commerce

[25] On the contrary, it may be remarked, that if two pounds of diluted sulphuric acid be mixed with three pounds of snow, the temperature of the snow will immediately be reduced 55 degrees, or from 32° to —23°.

at the temperature of 56°, and of the specific gravity of 1.844, and fresh oil of vitriol and fresh water were taken for every distinct experiment.

The effect produced by the mixture of sulphuric acid and water is well known; but no writer has noticed the property which heated sulphuric acid has of retaining its caloric, or of imparting it slower than most other fluid bodies usually do. I have observed that the workmen frequently pour this article from the retorts into large empty glass bottles called carboys, at a temperature of from 190° to 200° without inconvenience; whereas, if water were used at the same, or even at a lower temperature, it would not fail to split them in an instant.

I. A Table of the Temperatures produced by the Mixture of Sulphuric Acid and Water.

Weight of water used in each Experiment.	Sulph. acid in pounds.	Acquired Temper. of Fahrenht.	Weight of water used in each Experiment.	Sulph. acid in pounds.	Acquired Temper. of Fahrenht.
10 pounds avoirdupois at 50°.	1	78°	10 pounds avoirdupois at 50°.	14	236°
	2	100		15	241
	3	110		16	246
	4	128		17	250
	5	138		18	253
	6	144		19	256
	7	156		20	258
	8	168		25	266
	9	186			—
	10	204		27	265
	11	214		*30	264
	12	222		35	258
	13	229		40	248

* An experiment was made with the same proportion of the ingredients in ounces instead of pounds; viz. ten ounces of

In making these experiments, I observed that in the two first it required five minutes for the mixture to arrive at the maximum of temperature; that afterwards it acquired the maximum in two minutes; and that when the weight of the sulphuric acid was more than half that of the water with which it was mixed, the heat was evolved with still greater rapidity, till at last the change seemed to be instantaneous.

The accurate performance of these experiments is attended with some difficulty, on account of the steam which arises from the surface of the mixture; for when the weights of the sulphuric acid exceeded those of the water, the steam, in some of the experiments, was so great as to render it very difficult to determine the exact point to which the mercury had ascended. In the latter experiments, when the weight of the acid amounted to nearly double that of the water, although the temperature occasioned by the mixture of those fluids was higher, little or no vapour was formed, and the graduation of the thermometer could, at each experiment, be observed with exactness.

Fourcroy, in his *System of Chemical Knowledge*, relates [26] that "the mixture of water and sulphuric acid which produces the greatest heat, consists of four parts of acid and one of water, and that the

water at 50° were mixed with thirty ounces of sulphuric acid at 56°; and though the mixture was made in favourable circumstances, the temperature did not exceed 246° of Fahrenheit.

[26] Nicholson's *Translation of Fourcroy*, vol. ii. page 94.

temperature rises to 120° of Reaumur's scale," equal to 302° of Fahrenheit. This statement I find to be incorrect; for the real maximum of temperature is obtained by a mixture of between two and three parts of acid to one of water; and the greatest elevation of temperature which I have been able to procure, is that of 266°. Had the experiments, however, been made in summer, it is probable the temperature might have been raised some degrees higher.

It may be necessary to caution those who have not been accustomed to chemical operations, and yet would like to repeat these experiments, to be careful to add the oil of vitriol to the water, and not to reverse it by pouring the water upon the acid, which would be apt to occasion a part of the mixture to fly up, and endanger the face and the clothes of the operator.

As some persons may be surprised to see an account of experiments made on so large a scale, and with so great an expenditure of sulphuric acid as must be required where *fresh* acid is taken for every distinct experiment, as was the case here, it may be advisable just to remark, that in such a manufactory as mine, in which I have sometimes used 30 or 40 cwt. of sulphuric acid in a week, and in which diluted acid is used for a variety of processes, similar experiments can at any time be made without much trouble, or without incurring any actual expense.

Several years ago, I was frequently applied to by persons in different parts of the kingdom, for in-

structions respecting some mode of ascertaining the quantity of acid in diluted sulphuric acid of various specific gravities; and I invariably referred them to Dr. Kirwan's Table, which was published in the year 1793 in the fourth volume of the *Transactions of the Royal Irish Academy*. This, however, generally proved unsatisfactory to those who applied to me, inasmuch as few manufacturers could understand how to accommodate that table to the common oil of vitriol, or make it applicable to any practical purpose. This has arisen from the circumstance of Dr. Kirwan having taken for his standard sulphuric acid as it exists in sulphate of potash, instead of employing the oil of vitriol of commerce.

Having found the inconvenience of this in my own concerns, I long ago formed a table for private use, founded upon the sulphuric acid of commerce, by diluting that acid with several successive portions of water; a table which I employed for several years with great advantage. But as this table was formed at a temperature above the mean temperature of the atmosphere, and its range was too confined to be of use in every instance, I resolved to undertake the formation of a new one that would be more generally useful, and which should proceed by very slow but regular gradations, up to the highest point of dilution that any consumer of sulphuric acid would be likely to require[27].

[27] The first line of the table shows the specific gravity of a mixture of one part water and 100 parts of strong sulphuric

Having at no small expense of time and labour completed this table, it will be inserted in this Essay, from a persuasion that it will prove useful to many individuals in various branches of trade and manufacture.

To compose this table, I might have taken *purified* sulphuric acid, *i. e.* such as had undergone an actual distillation; but as this is an article which is never employed but for philosophical purposes, I thought it better to make use of the common acid, and to take as good a sample of that kind as could possibly be procured. I therefore chose some of my own manufacture, made in the usual way, and concentrated, as is common in large manufactories, by steaming it in a boiler of lead, and finishing it in a retort of glass. When I began the experiments of dilution, the atmosphere of the room was at 60°, and the acid was of the specific gravity of 1.8494, which, at this temperature [28], is as strong as it is ever sold.

In order to form the annexed table, I proceeded as follows:

I first accurately weighed ten thousand grains of the acid into a stoppered bottle of glass, and then added to it 100 grains of pure water [29]. When the mixture was become cool, after having been suffi-

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acid. The latter, the specific gravity of one part of sulphuric acid mixed with 100 parts of water.

[28] For the difference which is occasioned in the specific gravity of sulphuric acid by change of temperature, consult Table III. in this Essay.

ciently agitated, the specific gravity of it was taken, and the result forms the first line of the table. In this way I continued to dilute the acid with successive portions of water, taking care to let it resta sufficient time between each addition of the water, that a complete union between the acid and the water might take place; having found by experiment that a mixture of sulphuric acid and water, even after it has become cold, requires several hours to arrive at the maximum of condensation. I took also the precaution of keeping it in stoppered bottles, that it might not imbibe water from the atmosphere, and frequently agitated it during each interval. And in order to attain as great accuracy as possible, I procured a specific-gravity-bottle larger than usual, one that holds nearly ten ounces of water, and with a stem so small that at the part to which the fluid rises when properly filled, a single drop of the liquor will occasion a rise of nearly one-sixteenth of an inch.

The balance which I made use of in these experiments will turn with the twentieth part of a grain; and as the acids will erode the common scale-dishes, if dropt upon them, and endanger the accuracy of a result, I have long been in the habit of using those made of Wedgwood's ware, and such were employed in making this table. Those parts of the

[29] In diluting sulphuric acid, it is usual, and safer, to add the acid by degrees to the water, and not the water to the acid; but with this very small quantity of water, such caution was not necessary.

table which have a star opposite to them, were founded on actual experiment; the intermediate ones were the results of calculation.

Since I concluded these experiments it occurred to me, that it might be useful to some manufacturers to know the quantity of acid per cent. in diluted acid of any given strength; I have therefore calculated the quantity in each, and annexed it. The column of *ounces* and *drachms* is added for the use of those who are accustomed to this mode of reckoning, and also for those who are not conversant with the usual method of stating specific gravities; and it is calculated on the supposition of the wine-pint holding exactly sixteen ounces avoirdupois of pure water.

It is a convenient way of measuring, to have a glass bottle with a narrow neck, holding rather more than a pint of water, with a mark on the stem at the place to which the water ascends when it contains exactly 16 ounces avoirdupois of that fluid. It was formerly understood that the standard wine-pint was the exact measure of 16 ounces of pure water; but in opposition to a decision made by the Board of Excise in the year 1688, it has since been determined that the English wine-pint holds 7272 grains of pure water, which is 272 grains more than an avoirdupois pound. However, as it has long been usual, for all common purposes, still to consider it of the capacity of 16 ounces avoirdupois, I have taken it at that in the construction of this table.

If the wine-pint of water (7272 grains) be divided by 16, this will give 454½ grains for the weight of the ounce measure of water, which if expressed in decimal figures, will stand thus, 454.5; and it is worth remarking, that there is a singular coincidence here which is very favourable to the memory, *viz.* the pint measure is *seven two—seven two*; and the ounce measure, *four five—four five*.

The sulphuric acid which is consumed in these kingdoms amounts to upwards of three thousand tons annually, of which the greater part is used in a state of dilution. For the purposes of dissolving iron or zinc, it should be diluted with at least five or six times its weight of water. Sulphuric acid is consumed in large quantities by bleachers, for making the oxymuriate of lime, and they always use it in a state of dilution. The calico-printers also use this acid in various states of dilution, for making what they call sours.

To these, and other manufacturers, this table will be of use, not only in assisting them in the formation of diluted acid of any given strength, but it will enable them at any time to ascertain whether their servants have observed due care in making the different preparations, which is a matter of great moment; for it often happens, that for want of this the printer and manufacturer suffer great loss, and the printed goods sustain an irreparable injury.

I need scarcely add that the sulphuric-acid-makers themselves may also derive benefit from attending to this table; for, by its assistance, they can at all

times form a pretty accurate estimate of the value of any sample of the unrectified acid, or of the weak acid while in the state of operation in any of their leaden chambers.

II. A Table of the Specific Gravities of Sulphuric Acid, when diluted with different portions of water, constructed for the use of manufacturers; being the result of experiments made with the strongest sulphuric acid of commerce. The specific gravities taken at the temperature of 60°.

Drachms of Acid.	Drachms of Water.	Specific Gravity.	Weight of the Wine-pint.		Acid per Cent.
			Oz.	Drms.	
100 Drachms Sulph. Acid. Sp. Grav. 1.8494.	*1	1.8484	29	9¼	99.009
	*2	1.8465	29	8¼	98.039
	*3	1.8445	29	8¼	97.087
	*4	1.8416	29	7½	96.153
	*5	1.8387	29	6¼	95.238
	6	1.8358	29	6	94.339
	*7	1.8319	29	5	93.457
	8	1.8270	29	3¼	92.509
	9	1.8222	29	2½	91.743
	*10	1.8163	29	1	90.909
	11	1.8104	28	15½	90.090
	12	1.8046	28	14	89.285
	13	1.7988	28	12½	88.495
	14	1.7929	28	11	87.719
	*15	1.7880	28	9¼	86.956
	16	1.7821	28	8	86.206
	17	1.7744	28	6¼	85.470
	18	1.7666	28	4¼	84.745
	19	1.7588	28	2¼	84.033
	20	1.7510	28	0¼	83.333
	*21	1.7431	27	14¼	82.644
	22	1.7353	27	12¼	81.967
	23	1.7275	27	10¼	81.300
	24	1.7207	27	8½	80.645
	25	1.7138	27	6¼	80.000
	26	1.7070	27	5	79.365
	*27	1.7002	27	3¼	78.740

Drachms of Acid.	Drachms of Water.	Specific Gravity.	Weight of the Wine-pint.		Acid per Cent.
			Oz.	Drms.	
100 Drachms Sulph. Acid. Sp. Grav. 1.8494.	28	1.6933	27	1½	78.125
	29	1.6865	26	15¼	77.519
	30	1.6796	26	14	76.923
	31	1.6728	26	12¾	76.335
	32	1.6660	26	10½	75.757
	*33	1.6582	26	8½	75.187
	34	1.6523	26	7	74.626
	35	1.6464	26	5½	74.074
	36	1.6406	26	4	73.529
	37	1.6348	26	2½	72.992
	38	1.6289	26	1	72.463
	39	1.6230	25	15½	71.942
	*40	1.6171	25	14	71.428
	41	1.6113	25	12½	70.921
	42	1.6054	25	11	70.422
	43	1.5995	25	9½	69.930
	44	1.5937	25	8	69.444
	*45	1.5879	25	6½	68.965
	46	1.5820	25	5	68.493
	47	1.5761	25	3½	68.027
	48	1.5703	25	2	67.567
	49	1.5645	25	0½	67.114
	50	1.5585	24	15	66.666
	51	1.5526	24	13½	66.225
	52	1.5478	24	12¼	65.789
	53	1.5429	24	11	65.359
	*54	1.5390	24	10	64.935
	55	1.5351	24	9	64.516
	56	1.5312	24	8	64.102
	57	1.5273	24	7	63.694
	58	1.5234	24	6	63.291
	59	1.5195	24	5	62.893
	60	1.5156	24	4	62.500
	61	1.5117	24	3	62.111
	*62	1.5078	24	2	61.728
	63	1.5039	24	1	61.349
	64	1.5000	24	0	60.975
	65	1.4960	23	15	60.606
	66	1.4921	23	14	60.240
	67	1.4882	23	13	59.880
	68	1.4843	23	12	59.523

Drachms of Acid.	Drachms of Water.	Specific Gravity.	Weight of the Wine pint.		Acid per Cent.
			Oz.	Drms.	
100 Drachms	69	1.4804	23	11	59.171
Sulph. Acid.	*70	1.4765	23	10	58.823
Sp. Grav.	71	1.4726	23	9	58.481
1.8494.	72	1.4687	23	8	58.139
	73	1.4648	23	7	57.803
	74.	1.4609	23	6	57.471
	75	1.4570	23	5	57.142
	76	1.4531	23	4	56.818
	77	1.4502	23	3¼	56.497
	*78	1.4473	23	2½	56.179
	79	1.4433	23	1¾	55.865
	80	1.4395	23	0½	55.555
	81	1.4365	22	15¼	55.248
	82	1.4336	22	15	54.945
	83	1.4306	22	14¼	54.644
	84	1.4276	22	13½	54.347
	85	1.4257	22	12¼	54.054
	*86	1.4218	22	12	53.763
	87	1.4189	22	11¼	53.475
	88	1.4160	22	10½	53.191
	89	1.4130	22	9¼	52.910
	90	1.4101	22	9	52.631
	91	1.4072	22	8½	52.356
	92	1.4042	22	7¼	52.083
	93	1.4013	22	6¼	51.813
	*94	1.3984	22	6	51.546
	95	1.3955	22	5¼	51.282
	96	1.3926	22	4½	51.020
	97	1.3906	22	4	50.761
	98	1.3886	22	3½	50.505
	99	1.3867	22	3	50.256
	*100	1.3848	22	2½	50.000
	105	1.3730	21	15½	48.780
	*110	1.3632	21	13	47.619
	115	1.3535	21	10½	46.511
	*120	1.3437	21	8	45.454
	125	1.3359	21	6	44.444
	*130	1.3281	21	4	43.478
	135	1.3203	21	2	42.553
	*140	1.3125	21	0	41.666
	145	1.3056	20	14¼	40.816

Drachms of Acid.	Drachms of Water.	Specific Gravity.	Weight of the Wine-pint.		Acid per Cent.
			Oz.	Drms.	
100 Drachms Sulph. Acid. Sp. Grav. 1.8494.	*150	1.2988	20	12½	40.000
	155	1.2919	20	10¼	39.215
	*160	1.2851	20	9	38.461
	165	1.2783	20	7¼	37.735
	170	1.2724	20	5¼	37.037
	175	1.2676	20	4½	36.363
	*180	1.2627	20	3¼	35.714
	185	1.2568	20	1¼	35.087
	190	1.2520	20	0¼	34.482
	195	1.2470	19	15¼	33.898
	*200	1.2421	19	14	33.333
	210	1.2343	19	12	32.258
	*220	1.2265	19	10	31.250
	230	1.2187	19	8	30.303
	*240	1.2129	19	6½	29.411
	250	1.2060	19	4¼	28.571
	*260	1.1992	19	3	27.777
	270	1.1933	19	1½	27.027
	*280	1.1875	19	0	26.315
	290	1.1825	18	14¼	25.641
	*300	1.1776	18	13½	25.000
	310	1.1728	18	12¼	24.390
	320	1.1679	18	11	23.809
	330	1.1630	18	9¼	23.255
	*340	1.1582	18	8½	22.727
	350	1.1552	18	7¼	22.222
	360	1.1523	18	7	21.739
	370	1.1494	18	6¼	21.276
	*380	1.1464	18	5½	20.833
	390	1.1426	18	4½	20.408
	400	1.1338	18	2¼	20.000
	*420	1.1328	18	2	19.230
	440	1.1279	18	0¼	18.518
	*460	1.1240	17	15¼	17.857
	480	1.1181	17	14¼	17.241
	*500	1.1132	17	13	16.666
	*550	1.1054	17	11	15.384
	*600	1.0966	17	8¼	14.285
	*650	1.0898	17	7	13.333
	*700	1.0839	17	5½	12.500
	*750	1.0781	17	4	11.764

Drachms of Acid.	Drachms of Water.	Specific Gravity.	Weight of the Wine-pint.		Acid per Cent.
			Oz.	Drms.	
100 Drachms Sulph. Acid. Sp. Grav. 1.8494.	*800	1.0732	17	$2\frac{1}{4}$	11.111
	*850	1.0693	17	$1\frac{1}{2}$	10.526
	*900	1.0664	17	1	10.000
	*950	1.0625	17	0	9.523
	*1000	1.0602	16	$15\frac{1}{2}$	9.090
	*1100	1.0546	16	14	8.333
	*1200	1.0507	16	13	7.692
	*1300	1.0488	16	$12\frac{1}{2}$	7.142
	*1400	1.0458	16	$11\frac{3}{4}$	6.666
	*1500	1.0429	16	11	6.250
	1600	1.0390	16	10	5.882
	1700	1.0370	16	$9\frac{1}{2}$	5.555
	*1800	1.0351	16	9	5.263
	1900	1.0337	16	$8\frac{5}{8}$	5.000
	*2000	1.0322	16	$8\frac{1}{4}$	4.761
	*2250	1.0283	16	$7\frac{1}{4}$	4.255
	*2500	1.0254	16	$6\frac{1}{2}$	3.846
	*2750	1.0234	16	6	3.508
	*3000	1.0214	16	$5\frac{1}{2}$	3.225
	*3500	1.0185	16	$4\frac{3}{4}$	2.777
	*4000	1.0166	16	$4\frac{1}{4}$	2.439
	*4500	1.0146	16	$3\frac{3}{4}$	2.173
	*5000	1.0127	16	$3\frac{1}{4}$	1.960
	5500	1.0117	16	3	1.785
	*6000	1.0107	16	$2\frac{3}{4}$	1.639
	*6500	1.0102	16	$2\frac{3}{4}$	1.515
	*7000	1.0098	16	$2\frac{1}{2}$	1.408
	7500	1.0093	16	$2\frac{3}{8}$	1.315
	*8000	1.0088	16	$2\frac{1}{4}$	1.234
	8500	1.0083	16	$2\frac{1}{8}$	1.162
	*9000	1.0078	16	2	1.098
	9500	1.0073	16	$1\frac{7}{8}$	1.041
	*10000	1.0068	16	$1\frac{3}{4}$	0.990

This table was compiled in the year 1812, and printed in the *Philosophical Magazine* for the September of that year; but since its publication I have been informed there is a table by Vauquelin, in one of the volumes of the *Annales de Chimie*,

on a similar plan. To this I have referred [30]; and on comparison, allowing for the difference in the strength of the acid which we severally employed, I find that his table and mine very nearly coincide, except in one instance, and in this there is a very material disagreement. His table, however, is a very confined one, for it affords only twelve examples of the specific gravity of diluted sulphuric acid; whereas mine contains no less than 183 such examples.

In my table it is stated that the diluted acid of the specific gravity of 1.023 contains only 3.508 per cent. of the strongest sulphuric acid of commerce; whereas he says it contains 6.600 per cent. of acid and 93.400 of water. This has induced me to repeat so much of the experiment as was necessary for satisfaction on this point, and I find that this repetition only confirms the accuracy of the experiments on which my table was founded.

However, as the sulphuric acid which Vauquelin employed had a specific gravity only of 1.8420, I procured some acid exactly of the same strength; and having carefully mixed 66 drachms of it with 934 drachms of pure water, both measured by weight, and left the mixture at rest a proper time for a complete combination to be effected, I found its specific gravity at 60° of Fahrenheit to be 1.0474, instead of 1.0230 as Vauquelin has stated. Pur-

[30] *Annales de Chimie*, vol. lxxvi. page 260.

suing the experiment still further, I found that 66 drachms of such acid, instead of taking 934 drachms of water, actually require 2084 drachms of that fluid to reduce the whole to the specific gravity in question, viz. that of 1.023.

As the foregoing table proceeds entirely on the dilution of the concentrated sulphuric acid with different portions of water, it will not be misplaced if I add a caution respecting the *keeping* of this acid in a state of dilution, which in certain cases is highly dangerous.

Some years ago, being in conversation with a sulphuric-acid-maker, I inadvertently remarked that this acid might be rendered colourless and pellucid without submitting it to the process of rectification in glass, and I told him how the thing might be effected.

Delighted with this intelligence, on his return home he immediately put the process to the test, without having previously communicated his intention to his partner, and he actually prepared more than one hundred carboys, holding about 150lb each, of this weak acid, in readiness to be sent off to customers whom he had hitherto supplied with the usual sulphuric acid of commerce, and who would not, as he imagined, perceive the difference.

But, unfortunately for this crafty individual, it was in the midst of winter when this grand scheme of sophistication was adopted, and every carboy

which he had prepared became frozen. Bottle after bottle, therefore, burst by the expansion of the acid in the act of freezing; and if he had not adopted the method of filling all the large vessels on the premises with tepid water, and immersing the packed carboys in it, not a single bottle would have been saved from the general wreck.

To prevent accidents from the inadvertent mixture of water with oil of vitriol, it cannot be too generally known, that sulphuric acid diluted to the specific gravity of 1.780, which is twenty-eight ounces and a half to the wine-pint, will freeze *much sooner* than water[31]. If 12 or 13 per cent. of water be mixed with the strongest sulphuric acid of commerce, it will form an acid of about this specific gravity, and such acid would freeze at some degrees of temperature higher than that at which water congeals. Mr. Dalton has, however, by experiment ascertained a curious fact which had been hinted by Mr. Keir, respecting the dilution of sulphuric acid[32], viz. that if the liquid acid be of greater or less specific gravity, so as to contain even one per cent. more or less real acid, in that case it cannot be frozen in a temperature above 32°.

It was known to many of the old chemists that concentrated sulphuric acid would congeal at a very

[31] Keir, *Philosophical Transactions*, part ii. for 1787.
[32] See *New System of Chemical Philosophy*, page 406.

low temperature; but this very curious and singular property respecting the dilution of sulphuric acid was first noticed in this country by Mr. Keir.

From the experiments of this eminent chemist, it appears that there is a certain degree of strength at which sulphuric acid proves more congealable even than water. He exposed concentrated sulphuric acid to a frosty air in *open* vessels, and when it had imbibed enough water from the atmosphere to reduce it to about 1.780 it became congealed, and the congealed part, when thawed, was found to be of the standard of easiest freezing. Afterwards, in another experiment, he found the congealed part to thaw, in the open air, even while the cold increased, the continued absorption of moisture having weakened it below the degree of congelation. It is of importance that these facts should be known by all persons who either manufacture or employ sulphuric acid. I am inclined to think that in *some* seasons it would be dangerous to keep the acid in glass vessels, of a specific gravity any where between 1.770 and 1.790, as such acid would be liable to freeze in an extremely hard winter. When it is diluted much below 1.770, I should imagine it would be perfectly safe. A very scientific and experienced manufacturer of sulphuric acid has assured me that he has often sold it to the bleachers, during some very long and severe frosts, at a specific gravity of 1.710, and that in such cases no inconvenience from its becoming congealed ever occurred.

The affinities of sulphuric acid are in the following order:

Barytes,
Strontites,
Potash,
Soda,
Lime,
Magnesia,
Ammonia.

The boiling point of the best sulphuric acid of commerce, viz. that of 1.848, according to Mr. Dalton, on whom the utmost reliance may be placed, is 590° of Fahrenheit; but if it contain one per cent. more of acid, which would give it a specific gravity of 1.849, the boiling point will be raised to 605°, and if at the temperature of 60° it be one degree higher, viz. 1.850, it will not boil until it be heated to 620°.[33]

In a commercial point of view, and for every purpose of philosophical chemistry, it is of importance to become acquainted with the variations in the specific gravity of this acid in consequence of change of temperature. I know, however, of no one except Kirwan who has given any information on the subject; and in my opinion he has been peculiarly unfortunate in having made choice of *diluted* acid for his experiments, instead of the best concentrated acid[34]. For to most persons, and especially those

[33] Dalton's *Chemical Philosophy*, page 404.

[34] The account of these experiments by Dr. Kirwan, may be seen in Nicholson's *quarto Journal*, vol. iii. page 211.

who are large buyers of sulphuric acid, it must surely be of more importance to know what the strong sulphuric acid of commerce ought to be in all the variety of temperatures to which this climate is liable. To supply this desideratum, I undertook a series of experiments with such acid, and the several results have enabled me to construct the following table; which, in order that it might embrace every possible exigency, has been extended to 192 degrees of Fahrenheit.

III. A Table of the Variations in the Specific Gravity of concentrated Sulphuric Acid, by change of Temperature. Barometer 29.5 inches.

Temperature according to Fahr.	Contents in Grains, of a bottle holding 4266 grains of pure water, at 42.5 deg. of Fahr.	Specific Gravities.
10°	8000	1.8752
20	7964	1.8668
24	7952	1.8640
27	7940	1.8612
30	7932	1.8593
32	7920	1.8565
36	7912	1.8546
38	7906	1.8532
40	7904	1.8527
42	7901	1.8520
44	7898	1.8522
46	7895	1.8519
48	7892	1.8517
52	7886	1.8511
56	7880	1.8501
60	7864	1.8468
63	7854	1.8449
68	7846	1.8435
70	7842	1.8430
74	7833	1.8413
80	7816	1.8381

Temperature according to Fahr.	Contents in Grains, of a bottle holding 4266 grains of pure water, at 42.5 deg. of Fahr.	Specific Gravities.
84°	7794	1.8343
88	7788	1.8346
92	7780	1.8349
96	7772	1.8343
102	7748	1.8308
108	7729	1.8280
112	7720	1.8267
120	7710	1.8270
126	7702	1.8277
134	7692	1.8279
140	7676	1.8280
146	7648	1.8248
154	7632	1.8258
162	7610	1.8240
170	7582	1.8225
178	7567	1.8233
184	7558	1.8247
192	7546	1.8271

It must be understood, that in forming this table, the low degrees of temperature were produced by immersing a vessel containing the sulphuric acid in a frigorific mixture of snow and muriate of soda; and that the high temperatures were obtained by gradually heating the specific-gravity-bottle containing the same acid, before a common fire. Some allowance must therefore be made for the contraction and expansion of the glass, and which would, in some measure, alter the capacity of the containing vessel; but this is unavoidable. In each experiment the acid was poured from the phial, and thoroughly mixed, in order to be sure that the temperature was uniform before the thermometer was immersed in it.

From these experiments it appears that a vessel capable of containing 8000 grains of concentrated sulphuric acid at 10° of Fahrenheit, will not hold more than 7546 grains of this acid if at the temperature of 192°, and that sulphuric acid which is of the specific gravity of 1.8752 at 10°, will become of the specific gravity of 1.8271 when brought within 20 degrees of the temperature of boiling water.

It must, however, be remarked, that the chief design in constructing this table was to furnish the buyers and sellers of sulphuric acid with a scale by which they might ascertain the proper specific gravity of this acid at all temperatures. For instance, 1.845 is well known to be the proper strength at the temperature of 63°; but by the inspection of this table it will appear, that, when the atmosphere has for some time been at the temperature of 36°, such acid must be deficient in strength if it does not reach the specific gravity of 1.8546.

It has been ascertained that the maximum density of water is at the temperature of 42° 5, and that it becomes specifically lighter, whether it be heated above or cooled below that point. In making the foregoing table, therefore, it was necessary, in the first place, to fix the weight of the bottle of pure water at the temperature of 42° 5. This I found to be 4266 grains, and this I made the divisor in every case from 10° up to 42° inclusive. After this, the weight of the water was taken at 44°, and at every other degree between that and 192°; and in calculating the specific gravity of the sul-

phuric acid at 44°, and at all the higher temperatures, the weight of the acid in every instance was divided by the weight of the same measure of water at the corresponding temperature. This method of constructing the table (and I could not devise any other that would not have presented still greater difficulties) will perhaps account for several anomalies in the specific gravities of the acid when heated above 84°. For instance, the acid at 96° appears to have the same relative weight as at the temperature of 84°; also the acid at 108° and at 140° seems to have the same specific gravity. This irregularity may be accounted for by supposing that sulphuric acid in its expansion, observes a different law from that of pure water, which, in the formation of this table, as has been before noticed, was made the divisor in every instance [35].

Mr. Dalton has remarked that "it is a mistaken notion, that the common sulphuric acid of commerce is of the maximum strength, though it is of the maximum density nearly. The fact is, acid nearly of the maximum strength varies very little in its specific gravity, by the addition or subtraction of a small quantity of water. The specific gravity ought not therefore to be the criterion of strength in acids above 70 per cent.; the temperature at which they boil is a much better criterion, because it admits of a range of 12° or 15° for one

[35] A new table of the expansion of water by increase of temperature, will be given in the second volume of this work, in the Essay on Water.

per cent. of acid. Or the strength may be found by determining what quantity of water must be added to reduce the acid to some known strength, as that of the glacial acid, of 1.78 specific gravity."

The following Table constructed by Mr. Dalton, shows the boiling point at various degrees of density.

IV. Mr. Dalton's Table of the Quantity of dry Acid in 100 parts of liquid Sulphuric Acid, at the temperature of 60°; and its Boiling Point at different degrees of Density.

Atoms. Acid.	Atoms. Water.	Acid per Cent. by weight.	Acid per Cent. by measure.	Specific Gravity.	Boiling Point.
1	+ 0	100	unknown.	unknown.	unknown.
1	+ 1	81	150	1.850	620°
		80	148	1.849	605
		79	146	1.848	590
		78	144	1.847	575
		77	142	1.845	560
		76	140	1.842	545
		75	138	1.838	530
		74	135	1.833	515
		73	133	1.827	501
		72	131	1.819	487
		71	129	1.810	473
		70	126	1.801	460
		69	124	1.791	447
		68	121	1.780	435
1	+ 2	67	118	1.769	422
		66	116	1.757	410
		65	113	1.744	400
		64	111	1.730	391
		63	108	1.715	382
		62	105	1.699	374
		61	103	1.684	367
		60	100	1.670	360
1	+ 3	58.6	97	1.650	350
		50	76	1.520	290
		40	56	1.408	260
1	+ 10	30	39	1.30+	240
1	+ 17	20	24	1.200	224
1	+ 38	10	11	1.10—	218

The subject must not be dismissed without adverting to the USES of this acid.—The USES of sulphuric acid are very numerous. It is employed in large quantities, as has been already mentioned, for preparing bleaching-powder; by dyers for dissolving indigo, and for other purposes; by calico-printers for preparing sours[36]; and by the manufacturing and the philosophical chemist, as a test for lead and barytes, and for a great variety of other purposes, some of which only can be enumerated.

The makers of the nitric and muriatic acids are large consumers of sulphuric acid; as also are the makers of sulphate of zinc, sal-ammoniac, phosphate of soda, Glauber's and other salts; as well as the manufacturers of Roman vitriol, Prussian blue, and some other colours.

Sulphuric acid is likewise employed by some modern farmers in the preparation of their seed-wheat, to prevent what is called the smut[37]; by the people who purify lemon-juice, when united to lime, in order to separate its acid in a crystalline form for the use of calico-printers and others[38]; and by the makers of glass to convert the muriate of potash, which is one of their residuums, into sulphate of potash, an article which has lately been

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[36] See Essay IV, page 266.

[37] The method of employing sulphuric acid in the preparation of seed-wheat is explained by Mr. James Jennings, in one of the volumes of the Bath *Agricultural Papers*. I think he recommends the dilution of one gallon of the acid with thirty gallons of water, and when the mixture has become cold, to steep the seed in it for 20 hours, and then to sow it before it be allowed to become dry.

[38] See the Essay on Citric Acid.

used by them as a substitute for soda. It is also consumed in large quantities by the manufacturers of tin-plate, by brass-founders, button-makers, japanners and gilders; to all of whom this acid is become absolutely necessary for the removal of the oxide which forms on the surface of the iron or the copper on which they work, and which, if not removed, would prevent or impede all their operations.

Sulphuric acid is likewise a necessary article to some paper-makers, to fell-mongers, and to tanners;—it is used in considerable quantities by the modern hatter in the operation of felting[39];—and it may be mentioned that refiners use it in the process of stripping metals;—oil-merchants, in refining rape-oil, which it effects by carbonizing the farinaceous matter and the mucilage;—and brewers in fining what is called *gray beer*[40]:—that the professors of pharmacy as well as the chemists are constant customers for sulphuric acid;—that it is employed in making the astringent and stomachic water of Rabe[41], and for other purposes of medicine, as well as surgery;—that distillers and rectifiers of ardent spirits consume it in still larger quantities;—that the makers of vinegar use it for the adulteration of that acid;—that many tons are annually consumed in the preparation of liquid blacking;—and that the aëronaut, at every ascension into the atmosphere, requires many hundred weights of sul-

[39] See an explanation of this in Essay I, page 41.

[40] Combrune *On the Theory and Practice of Brewing*, 4to, London, 1762, page 274.

[41] See Fourcroy's *System of Chemistry*, vol. viii. page 240.

phuric acid for the formation of the hydrogen gas, which renders the aërial machine buoyant in that subtile medium.

These are some of the principal uses of sulphuric acid which have occurred to me while writing this paper; and probably there are many more, some of which are not now present to my memory, and others of which I have no knowledge.

It has occurred to me that it may be useful to be able to see at one view, what minerals and native salts there are which contain sulphuric acid.—I have therefore made out the following list, omitting such as afford a trace only, or a very small quantity of this acid.

Sulphate of ALUMINA, or native alum.—This occurs on an estate belonging to Mr. Mackintosh at Hurlet, near Paisley, and as an incrustation on the alum-slate of Whitby in Yorkshire. It is found also in Norway, in Bohemia, and in other places in Europe, Africa, and America. There is another species found at Hurlet, called Rock-butter, which is a native alum, mixed with alumina and oxide of iron. A specimen which he calls plumose alum, from Brandenburg, was analysed by Klaproth [42], and found to consist of

Alumina	15.25
Oxide of iron	7.50
Potash	0 25
Sulphuric acid and water of crystallization	77. 0
	100. 0

[42] *Analytical Essays*, vol. ii. page 78.

The specimens of alum-slate from Hurlet have the most beautiful incrustations of plumose alum that can be conceived.

Alum-stone contains from 12 to 25 per cent. of sulphuric acid, and the mineral called *native argil* or *aluminite*, 21 per cent. of this acid.

Mascagnine, or native sulphate of AMMONIA.—This mineral substance occurs among the products of Etna and Vesuvius, and is also obtained from certain districts in Tuscany. Karsten named it Mascagnine from its discoverer Professor *Mascagni*. Its colours are yellowish-gray and lemon-yellow [43]. One hundred parts, according to Kirwan [44], contain

Ammonia . . .	29. 7
Sulphuric acid . .	55. 7
Water . . .	14.16

Sulphate of BARYTES.—This native production has already been amply described at pages 314 and 361 of this volume. Some of the crystals of this mineral are extremely beautiful. According to Withering, it is a compound of 32.8 sulphuric acid, and 67.2 barytes. A specimen from Berlin in Connecticut [45] was found to consist of

Pure barytes . .	57.33
Pure strontites . .	3.92
Sulphuric acid . .	33.50
Silica . . .	2.50
Oxide of iron and alumina	1.75
Water . . .	1.00
	100.00

[43] Jameson, vol. ii. page 339.
[44] Kirwan's *Mineralogy*, vol. ii. page 10.

The native sulphate of barytes of Europe is found to vary in its composition according to the places from whence it is obtained.

Celestine, or native sulphate of STRONTITES. This mineral is found at Inverness; in Yorkshire; and at other places in Great Britain; more particularly at Aust Passage in the neighbourhood of Bristol. Klaproth's analysis makes it to consist of

Strontites . . .	56.0
Sulphuric acid . .	42.0
	98.0

Some very fine specimens of crystallized sulphate of strontites have been procured from Strontian Island, Lake Erie, in the United States of America[46].

Sulphate of COBALT.—This is a native salt which has been found near Hanau in Germany. Its colour is a light flesh-red. It has a very caustic taste, and is soluble in water. It is a compound of sulphuric acid 19.74+oxide of cobalt 38.71+water 41.55=100 sulphate of cobalt. This analysis was made by M. Kopp, an account of which was published by Bucholz, with the analysis of other minerals[47].

Sulphate of COPPER, or native blue vitriol.—This mineral occurs in Pary's mine in the Isle of Anglesea; in the county of Wicklow in Ireland; and also

[45] American *Journal of Science*, vol. iv. page 327.
[46] Silliman's *Journal*, vol. iv. page 279.
[47] *Annales de Chimie*, vol. lxx. page 55.

in many other of the copper mines of Europe. Its colour is dark sky-blue. According to Berzelius it is composed of oxide of copper 32.13 sulphuric acid 31.57 water 36.30 = 100 sulphate of copper.

Glauberite.—This mineral is found imbedded in rock-salt at Villaruba, near Ocana in New Castile, in Spain. It was first analysed by Brongniart [48]. He found it to be composed of

Sulphate of lime . .	49.0
Sulphate of soda .	51.0
	100.0

Pitchy IRON *Ore*, or the pitchy bog-iron ore of Aikin.—This mineral occurs in a mine near Freyberg, and in the district of Pless in Upper Silesia [49]. Klaproth has analysed it, and found it to consist of [50]

Oxide of iron . .	67
Sulphuric acid and water	33
	100

IRON *vitriol*, or native sulphate of iron, occurs under a variety of forms in several coal-mines in this country and on the continent of Europe. A specimen of native sulphate of iron was analysed by Berzelius, and found to consist of

Oxide of iron . .	25.7
Sulphuric acid . .	28.9
Water of crystallization	45.4
	100.0

[48] Jameson, vol. ii. page 255.
[49] *Ibid.* page 299.
[50] Phillips's *Elements*, page 209.

LEAD *vitriol*, or native sulphate of lead, occurs at Penzance in Cornwall, at Pary's mine in the Isle of Anglesea, and at Lead-hills in Scotland. It is found also in Siberia and in the United States of America. A specimen from the Lead-hills was found by Klaproth [51] to consist of

Oxide of lead . .	70.50
Sulphuric acid .	25.75
Water of crystallization	2.25
	98.50

Sulphate of LIME is a mineral that is procured in great abundance at Chelaston near Derby, and at Beacon-hill near Newark. It is a compound of 32 lime, 30 of sulphuric acid, and 38 water. It is found also in various parts of North America, where it is employed as a manure. The *Anhydrite*, or *Muriacit* of Werner, contains a still larger portion of sulphuric acid. A specimen analysed by Klaproth was found to consist of

Sulphuric acid . .	56.50
Lime . . .	42 00
Muriate of soda . .	0.25
Loss . . .	1.25
	100.00

It occurs in beds in the salt-mines of Austria; in granular gypsum near Brunswick; and has sometimes been met with in the gypsum of Nottinghamshire [52].

[51] Klaproth's *Analytical Essays*, vol. ii. page 129.
[52] Jameson, vol. ii. page 248.

Sulphate of MAGNESIA is commonly found in spring water; it occurs at Hurlet near Paisley in connexion with native alum, and at various places on the continent of Europe, especially in the quicksilver mines of Idria; in the province of Andalusia in Spain; and in Bohemia. According to Kirwan[53] its constituent parts are sulphuric acid 29.46, magnesia 17, water of crystallization 53.54. In a cave in the Indiana territory in Kentucky, it is found perfectly crystallized in delicate white prisms, and in such abundance that the inhabitants carry it away by the waggon-load[54].

Corneous MERCURY, or horn quicksilver, occurs in most of the quicksilver mines. Its constituent parts, according to Klaproth, are

Oxide of mercury .	76.00
Muriatic acid . .	16.40
Sulphuric acid . .	7.60
	100.00

Egyptian NATRON.—This natural production is found in considerable quantity at the town of Nitria and other parts of Egypt. Klaproth analysed it[55], and found it to consist of

Subcarbonate of soda	32.6
Sulphate of soda .	20.8
Muriate of soda .	15.0
Water	31.6
	100.0

[53] Kirwan's *Mineralogy*, vol. ii. page 13.
[54] *American Journal of Science*, vol. i. page 49.
[55] Klaproth's *Analytical Essays*, vol. ii. page 61.

Native NITRE.—This production of Nature occurs in every quarter of the globe. The natural nitre of Molfetta in the kingdom of Naples consists, according to Klaproth, of

Nitrate of potash . .	42.55
Sulphate of lime . .	25 45
Carbonate of lime . .	30 40
Muriate of potash and loss	1.60
	100 00

Reussite occurs as an efflorescence in the country around Sedlitz, and is also found crystallized in flat six-sided prisms, and in aggregated acicular crystals. It appears to consist of

Sulphate of soda . .	66.04
Sulphate of magnesia .	31 35
Muriate of magnesia .	2.19
Sulphate of lime . .	0.42
	100.00

Sassoline.—This is a natural production found on the edges of some hot springs near Sasso, a town in the territory of Florence [56]. Its constituent parts are

Boracic acid . .	86 0
Sulphate of manganese and lime	14.0
	100.0

Red SILVER *ore.*—A specimen of this mineral, found near Freiberg, was analysed by Klaproth [57], and found to consist of

Silver	62.0
Reguline antimony . .	18 5
Sulphur	11.0
Concrete sulphuric acid .	8.5
	100.0

[56] Klaproth's *Analytical Essays*, vol. ii. page 72.
[57] *Ibid.* vol. i. page 134.

Sulphate of SODA, or native Glauber salt, occurs at Eger in Bohemia, efflorescent on meadow ground; on the banks of many salt lakes in Siberia and in Egypt. It is found also on the walls of old buildings, and sometimes on those of new buildings in many parts of the world [58]. It is found in small proportion in sea-water; but according to the analysis of the waters of the several spas at Cheltenham, by Professor Brande and myself, they contain from 10 to 23.5 grains of this salt in a wine-pint of the water [59]. A specimen of native sulphate of soda from Eger was found to consist of

Sulphate of soda .	67.024
Carbonate of soda .	16.333
Muriate of soda .	11.000
Carbonate of lime .	5.643
	100.000

Native SULPHURIC ACID has been mentioned already in a note at page 465. I learn from Professor Brande, that it was discovered by Baldassari, in the cavities of a small volcanic hill called Zoccolino, near Sienna [60]. Sulphuric acid is found in considerable quantity in urine, though it does not exist in the blood. The elder Rouelle showed this long ago, and Berzelius asserts that he believes it to be an essential constituent of the urine [61].

White vitriol, or native sulphate of ZINC, is found at Holywell in Fintshire, and in other parts

[58] Jameson's *Mineralogy*, vol. ii. page 316.
[59] *Journal of Science, &c.* vol. iii. page 54—72.
[60] Brande's *Manual of Chemistry*, vol. i. page 396.
[61] Rees's *Cyclopedia*, article "Urine."

of Europe. A specimen analysed by Klaproth afforded

Oxide of zinc . .	27.5
Oxide of manganese .	0.5
Sulphuric acid . .	22.0
Water . . .	50.0
	100.0

The law which governs the formation of the sulphuric salts is this:—In the neutral sulphates, the proportion of oxygen in the acid is to that of the base as 3 to 1. Thus, sulphate of soda is a compound of 1 proportional of soda 29.5, containing 7.5 of oxygen, and 1 proportional of sulphuric acid 37.5, containing 3 proportions=22.5 of oxygen. If the composition of any of the other neutral sulphates be examined, they will be found to be formed in the same manner.

I had an intention of giving an ample detail of the methods to be pursued in erecting a lead-house for the manufacture of sulphuric acid, having preserved every necessary document, and registered every precaution which appeared needful, should I have occasion to superintend this business; but when I began to put these materials into form for publication, I found that it would be impossible to render the account useful without entering into the minutiæ of the business; and there are really so many things to be attended to in its management, that I was afraid, had I done justice to the subject, this Essay would have extended to a length quite

inconsistent with the plan of these volumes; and might have become tedious to the generality of readers who are not actually interested in the manufacture of this acid.

For these reasons, I shall content myself with suggesting a few hints which may prove useful to this class of manufacturers; and with these conclude the Essay.

In the erection of leaden chambers, one of the first considerations should be to ascertain the exact height of the adjoining ground, and then to fix the floor of each chamber at least two feet above this level. This arrangement has two advantages. The first is this,—that when the floor of a leaden chamber is so much elevated above the path-way, any leakage which may be occasioned by a flaw in the bottom will be quickly perceived; and should it ever be required to convey the acid from the chambers along leaden spouts to a distant part of the manufactory, this elevation will allow of a regular fall sufficient for the purpose.

It is convenient to have a small well attached to every leaden chamber, either at one end or on one side of it, and lined with lead, for the reception of the acid from the floor of the said chamber. If the floor of such well be sunk two feet below the floor of the lead-house, and its sides rise a little higher than the surface of the liquor ever stands within the body of the house, it will be a useful receptacle; and the additional cost, at the time of erecting a chamber, is not worth consideration. By the re-

moval of a plug, at any time, this small vessel becomes quickly filled with acid; and as its sides rise above the level of the fluid within the chamber, no leakage can ever arise from it. Such an appendage is useful for ascertaining the strength of the acid, or for taking out any quantity of it, without opening the doors of the chambers, or disturbing the operation during the combustion of the sulphur.

Where plates or dishes of iron are used for supporting the burning sulphur, it is useful to place them at a small distance one above the other in tiers of two or three each. By such an arrangement the combustion on the lower plates will communicate heat to those immediately above them, and this will very much facilitate the burning of the old stuff, which in a large manufactory is usually mixed in a certain proportion with the fresh materials. It is also prudent to have a sheet of lead firmly suspended in the form of a penthouse over every set of these burning-pans, to prevent the droppings of the chambers from falling into them and checking the combustion.

I would have also a leaden pipe securely soldered into one side of every house a foot or two above the burning-pans, and furnished with a stop-cock for the occasional admission of atmospheric air[62]. I once had a provision of this kind, where the en-

[62] The true theory of the formation of sulphuric acid, by means of nitrous gas and atmospheric air, is well explained by Clement and Desormes in the *Annales de Chimie* for 1806, and also in the 17th volume of Nicholson's *Journal*

trance was through the floor of the chamber; and I considered the contrivance to be at times very advantageous. If such a pipe were furnished with a proper valve, the house would occasionally supply itself with atmospheric air, and that strain which the sides of a leaden chamber sometimes experience from the production of a vacuum would in this way be prevented.

I have thought, that in those houses which have only one door at the end for the admission of the combustible materials, it might be advantageous to affix a high chimney at the opposite end, with a valve that might be opened and shut at pleasure; for, by opening the door of the chamber, and then the valve of the chimney, such a powerful draught would be produced as would sweeten an oil of vitriol-house in less than half the time which is usually required for this operation: but whether the saving of time and the other obvious advantage of the subsequent charges of sulphur burning better, would be more than adequate to the extra loss of nitrous gas which this rapid draught would occasion, must depend upon the care and judgement of the superintendant of the operation; I have therefore merely thrown out the hint for the consideration of those who have had sufficient experience to enable them to judge of the probable result.

With respect to the retorting-house, one built *entirely* with bricks, as glass-houses are usually erected, is doubtless the best, as the gas from this process soon decays the beams and rafters of a

building erected in the common way. But whenever it may be necessary to employ a common building for this purpose, I would recommend it to the proprietor to give every piece of timber that is likely to be exposed to the fumes of the sulphurous gas, *several coats* of the pyroligneous acid tar, which at page 399 in this volume I have proposed for the preservation of wood in general.

In fixing the beds of retorts, various modes have been adopted by different manufacturers; but I am convinced that no method is so eligible upon the whole as that in which there is a separate and distinct fire for each retort: and when such fire-places are fitted up with hopper-doors, similar to those described in page 158 of this volume, the expense of fuel will be infinitely less than by those erected upon any other construction.

In concentrating the sulphuric acid in glass, some manufacturers have adopted an expedient for preserving the glass, which is of considerable advantage. In this process, the glass-retorts are often broken by the sudden jerks and spouting of the ponderous acid, occasioned by the formation of vapour, and the difficulty which the vapour has in escaping; but if a few small strips of platinum be put into each retort, the sulphuric acid will boil with a different kind of motion, and the sudden jerks mentioned above will not occur.

When the acid is sufficiently concentrated, the fire is usually taken out of the grates, and the acid in the retorts is allowed to remain in the sand-heats

until the next day, that the glasses may become sufficiently cool to be removed from the beds without danger of their being cracked by too sudden a change of temperature. A man then lifts the retorts one by one out of the sand, each retort containing 50 or 60 pounds of hot concentrated sulphuric acid, and this he pours into carboys that have been previously warmed to receive it.

This is a frightful and a dangerous task; and instances have occurred of men being confined to their beds for several months together, with inveterate burns occasioned by these retorts, loaded with sulphuric acid, having burst in their arms and thrown the acid over the legs and other parts of the body.

These accidents are adverted to, merely for the purpose of enabling me to speak of a method which has been adopted in some manufactories for preventing their occurrence. In these establishments the retorts are not taken out of the sand-heats, but are emptied by means of a syphon, which has a glass globe capable of holding a pint or more fixed upon the bend of the syphon. This globe has a small tube rising from the top of it for the purpose of exhausting it of air; and when it is to be used, and is fixed in the retort, the operator applies his mouth to the small tube which is attached to the globe, and gradually exhausts it of air, till the pressure of the atmosphere overcomes the weight of the oil of vitriol, and occasions it to flow in a continued stream through the syphon, until the retort is emptied. I

consider this a most important improvement; and, as the inventor is dead, I feel myself at liberty to disclose it to the public. One caution, however, must be added,—that care be taken to have the globe of the syphon made sufficiently capacious to prevent the danger which there would otherwise be of the operator drawing a portion of the sulphuric acid into his mouth,—a misfortune which did actually happen to the person who constructed the first syphon on this principle.

Of late years it has been the practice in many of the large establishments in this country and elsewhere, to concentrate sulphuric acid in vessels of platinum instead of glass. The design of this is to save the perpetual expense arising from the breakage of retorts, and to avoid the danger which attends the emptying the retorts of glass, in the manner usually practised. When I was in the habit of rectifying sulphuric acid, I had one of these vessels, and found it to be easily managed, and very economical. It had a cover of lead, secured by a water-lute. It held exactly thirty gallons, wine measure, and cost about 360*l*. It would, however, be very difficult at this time to procure such a vessel, in consequence of the present scarcity both of crude and malleable platinum.

In addition to these hints, it may be necessary to remark, that no one ought to begin the manufacture of sulphuric acid, or even to erect a lead-house for its preparation, without placing the whole work

under the direction of some judicious and experienced person, one who is well acquainted with all the difficulties, and knows how to surmount every obstacle.

It behoves me also to guard the unwary against engaging in this business, unless it be in their power to embark a large capital in the concern, and to manufacture sulphuric acid on a great scale. Some individuals may perhaps be disposed to erect one house to manufacture a quantity of sulphuric acid sufficient merely for their own consumption; but the expense of working a single chamber, with that of attending the steaming vessel day and night, and afterwards of concentrating the acid in glass, will absorb all the profit. This I can assert with confidence; for it is not merely a matter of opinion, but the actual result of my own experience.

ESSAY VIII.

ON

CITRIC ACID.

ESSAY VIII.

ON

CITRIC ACID.

" Nor be the Citron, Media's boast, unsung,
Though harsh its juice, and lingering on the tongue.
When the drug'd bowl, 'mid witching curses brew'd,
Wastes the pale youth by stepdame hate pursued,
Its powerful aid unbinds the muttered spell,
And frees the victim from the draught of hell."

SOTHEBY'S Virgil's *Georgics*, book ii.

THERE is a peculiar acid in the juice of lemons, citrons, limes, and a variety of other fruits, different in some of its properties from all others, and known to chemists by the name of the CITRIC ACID.

It does not appear that the ancients set any value on the juice of these fruits, except as an antidote against poison, or that they ever employed it in considerable quantities for any purpose whatever; though from some lines in Virgil's Georgics, part

of which I have taken as a motto for this Essay, it is evident they had a high opinion of its virtues in counteracting the effects of some deleterious drugs or vegetables.

Pliny tells us, though he says nothing of the fruit, that the *wood* of the citron-tree was highly esteemed in his time; that the best furniture and the most costly cabinet-work were made with it; and that very exorbitant sums were paid for citron tables by the wealthy citizens of Rome [1]. There is, however, some reason for believing that this was the product of a different tree from that which produces the fruit now known by the name of the citron.

As lemon juice can be procured with advantage only at one season of the year, and is apt, whatever care may have been taken with it, to spoil in keeping, on account of the sugar, the water, the extractive matter, and the mucilage which it contains, all of which tend to throw it into a state of fermentation, it became an object to chemists to divest it of these imperfections, and thus to procure the real acid of the fruit in a state of perfect purity.

In endeavouring to trace the history of the discoveries respecting citric acid, I examined, among other works, the *Chemical Dictionary* of Macquer, expecting to find some account of the experiments made on this acid in his time; but I was not able to find a single sentence, in either of the volumes, on lemon juice, or on citric acid. I am, however,

[1] Holland's *Translation of Pliny*, vol. i. page 395.

now informed that Mr. Leonhardi, who published a German edition of Macquer at Leipsic, in six volumes octavo, with considerable additions and observations of his own, has related some very interesting particulars respecting this acid.

Scheele and other practical men attempted to separate these matters by means of alcohol [2]: but this intermedium effects the desired purpose very imperfectly; for though it will divide the mucilage, it has not the power of separating the extractive matter or the sugar.

In the year 1774, M. Georgius, a Swedish chemist, published in the Stockholm Memoirs a process for separating the mucilage and concentrating the acid, by keeping the lemon juice for some time in a cool place in inverted bottles, and then exposing it to cold at some few degrees below the freezing point; and in this way to separate the water, which, with the remaining mucilage, freezes; and this frozen portion is directed to be repeatedly removed. The liquor is then submitted again and again to the action of the frost, till it is reduced to one-eighth of its original quantity. By this management none of the acid is lost; and when it is thus concentrated, it may be kept for many years without sustaining any injury.

On this process, to which there is little objection except the time required for its completion, and

[2] On the method of concentrating and preserving the citric acid by means of alcohol, see Brugnatelli, *Annales de Chimie*, vol. xii. page 148, and vol. xxvi. page 298.

that it can be effected only at one season of the year, it is necessary to remark, that care should be taken not to expose the juice to a degree of cold too intense, lest part of the acid also be congealed with the aqueous portion, and thus defeat the intention. Whereas, if it be submitted to the action of the frost when the thermometer is between 28° and 32°, and the ice be carefully removed as it forms, the juice may be reduced to an eighth part of its former bulk, and consequently increased in strength, because the remaining eighth will really be equal in its saturating power to the whole of the original acid.

This process will answer very well for domestic purposes, and the concentrated acid may be long preserved by mixing it with 7 or 8 times its weight of refined sugar in powder: but it affords no assistance in furnishing the concrete citric acid; for, after the juice has been thus condensed, still enough of the extractive matter will remain in it to prevent the crystallization of the acid.

After the publication of this paper by Georgius, a Mons. Du Buisson of Paris announced another method of concentrating and preserving lemon juice. This consisted in reducing its quantity by the action of a gradual heat, kept up for a considerable time, which has the effect of thickening the mucilaginous matter, and occasioning its separation in a glutinous mass on the surface of the liquor. When this is removed, the remaining juice may be preserved a long time unaltered.

Both these proposals may be viewed as approximations towards the development of the true method of purification, which was reserved for that enterprising and renowned Swedish chemist, who has immortalized his name by discoveries of far greater importance than that which is now under consideration.

The ingenious Scheele was the first who exhibited this acid in a solid form; and to accomplish this end, he adopted merely the same method which he had employed long before in the purification and crystallization of the tartaric acid.

It consists in separating the real acid by means of carbonate of lime, and then decomposing the citrate of lime by the intermedium of diluted sulphuric acid;—a process which has been universally adopted throughout Europe; there being no other means yet discovered of putting this acid into a crystalline form.

Having myself had some experience in this process by frequently superintending its progress, and more than once to the extent of several hogsheads of juice in one operation, I shall now, with some confidence in their correctness, proceed to give what appear to me to be the best directions for obtaining a successful and economical result.

The juice, which is imported in pipes and hogsheads, should be drawn off into a large open vessel; —a square vat made of fir is very proper for the purpose. In this vessel the juice is to be saturated

with lime, by the gradual addition of clean soft chalk, or whiting. Care must be taken to note down the quantity of carbonate of lime employed, which should be added till it occasions no further effervescence, and until the liquor shows no signs of acidity on test paper.

I have said that the chalk should be added very gradually, because otherwise the effervescence, by the disengagement of carbonic acid, will be so considerable as to occasion a great part of the contents of the vat to flow over and be lost.

If the proprietor of the establishment can devote a room to this purpose that is large enough to allow of the rolling in the full pipes of juice, the better way would be to put the intended quantity of whiting, or nearly the whole of it, all into the vat at first; to wet it well with water, and then to pump in the acid by degrees upon it; for in this way the effervescence is less, and the operation more manageable. If the cask containing the juice be rolled near to the vat, a small copper hand-pump may be put in at the bung-hole; and while one man is slowly pumping it into the vat, another should not cease to agitate the whiting; and whenever there is any danger of the mixture rising too high in the vessel, the operators will have only to rest a moment, and all will be safe. In this way the saturation will be complete, and it will be done in the least possible time.

In this process all the real acid of the lemon juice is absorbed by the calcareous earth; and when the

combination is completely formed, the citrate of lime, which is an insoluble salt, precipitates to the bottom of the vessel. When the whole of this has fallen, the supernatant liquor, which will be nearly tasteless, will be found to contain nothing besides the mucilage, except a portion of the essential oil of the rind of the fruit, some extractive and saccharine matter, and a little malic acid. This supernatant liquor is therefore to be drawn off, and the precipitate preserved for use.

If it be desirable for any part or the whole of the *malic* acid to be saved, it may readily be distinguished from the citric by the following properties: The malic acid does not crystallize; it precipitates silver, mercury, and lead, from their solutions in nitric acid, while citric acid has no such effect; and it forms a *soluble* salt when combined with lime.

It is usual, as I have seen in some of these establishments, to have plugs in the side of the vat, and at different heights, for the purpose of drawing off the supernatant liquor; but a syphon with a stop-cock is much more convenient; for with it the liquor may at any time be drawn off perfectly close, and the danger from a plug flying out be avoided.

When the supernatant liquor is removed by a syphon or otherwise, the precipitate, or citrate of lime, is to be passed through a sieve, and then frequently washed with warm water, until all the remaining mucilage and other soluble impurities be entirely washed off; which will be known, when the

whole has remained at rest for some time, by the water coming off clear and tasteless.

The precipitate, having been thus well washed, may be removed to another vessel, to be reserved till it is convenient to submit it to a second decomposition for the development of the citric acid. It is not necessary to dry this precipitate; but when it is to be used, let it be treated with diluted sulphuric acid in the following manner:—For every ten pounds of chalk or whiting, which has been employed in the process, it is necessary to take the quantity of nine pounds and a half of sulphuric acid of the specific gravity of 1.84 or 1.845, which is to be diluted with about seven gallons, or fifty-six pounds of water.

Proust employed diluted sulphuric acid of the specific gravity of 1.150; but on looking to my table of the specific gravity of diluted sulphuric acid, and which the reader may refer to at page 507 of this volume, I see that less than 4 parts of water will reduce the strongest sulphuric acid to that specific gravity; and I have found, as will hereafter be explained, that this is far short of the dilution that is necessary in order to produce the best result.

Some direct that, in order to decompose the citrate of lime completely, the whole should be made *hot* before the sulphuric acid is added: but this caution is quite superfluous; for, if the sulphuric acid be employed immediately after it has been diluted, the heat evolved on the mixture of the acid with

the water will alone serve for every purpose, and hence both time and fuel will be saved.

The diluted sulphuric acid is to be poured gradually upon the citrate of lime, and the whole mixture well stirred, for a considerable time, with a strong wooden spatula, that there may be no chance of any of the citrate remaining unbroken, and consequently unacted upon by the stronger acid.

The more effectually to guard against this, it is advisable, just before the last portions of sulphuric acid are added, to pass the whole mixture a second time through the sieve; for otherwise, notwithstanding the utmost care, some lumps of citrate of lime may still remain unpenetrated by the sulphuric acid, which would occasion a loss, and probably deception, and disappointment with respect to the final result.

In conducting this part of the process, I have noticed an appearance worth mentioning, which is this:—It being necessary to stir up the mass very frequently during the gradual addition of the sulphuric acid, I have observed that whenever the citrate of lime became nearly all decomposed, and the earth mostly saturated with sulphuric acid, the sulphate of lime precipitates quicker and quicker after every addition of this acid, and that the supernatant liquor considerably increases in quantity. The latter circumstance is occasioned by the increased density of the precipitate; and both appearances should always be looked for, as they afford a

good criterion for judging of the progress of the operation.

It is, however, proper to remark, that it would not be prudent for the operator to rely solely on these appearances; for, if he is to ensure the best possible management of the process, he must have recourse to the agency of chemical tests, as they will afford the only sure criterion by which the real state of the saturation of the lime can be known.

In many chemical operations, preparations of barytes, or a simple solution of this earth in water, are employed to detect the presence of sulphuric acid. But as citrate of barytes would immediately precipitate on the addition of barytic water to a solution of citric acid, this reagent cannot be conveniently employed to show when the exact quantity of sulphuric acid has been used. It is necessary therefore to look out for some other test, and this may be found in the joint employment of acetate of lead and nitric acid: and although this might have suggested itself to any chemist who had thought on the subject, I confess I am indebted for the idea to a person who has for several years past done much in the business, and who tells me he has long employed these two articles for this purpose with perfect success.

Whenever the saturation of the citrate of lime is nearly completed, and the operator is fearful of supersaturating it, all that is necessary is to take out a little of the clear liquor, after the precipitate has

subsided, to filtrate this liquor through paper, and then treat it with a few drops of acetate of lead. In this instance a citrate of lead will be formed, and precipitate, which precipitate will be immediately redissolved on the addition of a little of the nitric acid. On the contrary, should too much sulphuric acid have been used, there will be a mixed precipitate of citrate of lead and sulphate of lead; and the latter of these salts not being soluble in nitric acid, leads to the detection of an excess of the decomposing acid.

But to return to the process. The consequence of this affusion of the citrate of lime with sulphuric acid is this,—the sulphuric acid having a more powerful affinity with the lime, it combines with that earth immediately as it is poured upon the washed pulp of citrate of lime, and by this action it displaces the citric acid, which will then be found in the supernatant fluid.

The insoluble part of the mixture is now *sulphate* of lime; and when sufficient time has been allowed for the whole of this to precipitate, the fluid, which is the pure citric acid in a state of solution, may be drawn off for use.

In order, however, to procure the whole of the citric acid, more water must be poured on the sulphate of lime, and this washing repeated time after time, until the last portion of water comes off clear and tasteless.

In opposition to some directions which I have seen, I would advise that *cold* water be employed for these washings, as it will separate the fluid citric

acid from the precipitate, equally well with hot water, and will dissolve less of the sulphate of lime, which is a substance very unfavourable to the process of crystallization.

The whole of these washings are to be put together, and the mixed liquor is afterwards to be concentrated by evaporation.

Where the citric acid is intended to be made a considerable article of manufacture, a boiler of lead will be the most convenient for this purpose. It is, however, important to state that the bottom of this boiler should be made of one continued sheet of lead, not less than ten pounds to the foot, though five-pound lead will be sufficient for the sides. But where saving of expense is not the first object, it is best to have the vessel of one entire sheet of lead, by which all solder may be avoided. In this, the acid may be kept continually steaming without any danger, until it acquire the specific gravity of about 1.130.

In building the fire-place, it should be recollected that it, and its flues, must be entirely covered with a continued row of iron plates, which are to be supported at each end by the walls of the fire-place. These plates should not be less than one inch thick; and only six inches broad; because, when the plates are narrow, it will be less expense to repair them whenever any of them are worn out by the action of the fire. It is by these plates the leaden boiler is to be supported.

When the acid has acquired the specific gravity

of about 1.130, it will be prudent to withdraw the fire entirely, and proceed to remove the acid into a smaller vessel of lead, which should be so fixed within an iron pan of boiling water, as to form a complete balneum mariæ. In this bath the fluid may be further concentrated, by steaming, until it become so much reduced in bulk as to render it necessary to remove it into another water-bath, still smaller, but constructed in the same manner as the former.

In this last vessel the liquor is to be further evaporated until it acquire the consistence of very thin molasses, and then it should be watched with the greatest attention for the appearance of the pellicle, which may now be expected to rise on the surface. This pellicle will first show itself in small detached spots, and these, by degrees, will increase in size and number until the whole of the liquor is nearly covered with them. The concentrated citric acid should then be immediately taken out of the bath, and laid aside to cool and crystallize.

It is of the utmost consequence to attend to this circumstance; for so much of the fluid is evaporated before the pellicle appears, that, if it were to remain in the concentrating vessel half an hour longer, the whole might be carbonized and reduced to a useless and inert mass.

When removed, it should remain undisturbed for three or four days, that the largest possible quantity of crystals may be obtained from the liquor. After this time has elapsed, the mother-

water may be drained from the crystals; because, after that period, it will be in vain to expect a further increase without a further abstraction of water by a fresh evaporation.

It is likewise proper to remark that, however carefully the process may have been conducted, the whole of the calcareous earth will not precipitate while the supernatant liquor is loaded with the citric acid; for we know that this is capable of holding the citrate of lime in solution. Dizé having dissolved 100 parts of crystallized citric acid in pure water at 212°, found that the solution would take up 50 parts of calcareous citrate[3]. Hence some nicety is required in separating the lime, without adding an unnecessary and injurious quantity of sulphuric acid. It will therefore be advisable, as the acid becomes concentrated, to add occasionally a small portion of diluted sulphuric acid, which will arrest the lime, and precipitate it. To this end, the steaming should every now and then be discontinued for some hours, to allow time for the sulphate of lime to separate, which otherwise would prevent the crystallization of the pure citric acid; for Crell has shown, that a very small quantity of calcareous earth will have this effect. A single drop of sulphuric acid will, however, be a sufficient test, at any time, to show whether the concentrated citric acid holds any citrate of lime in solution. Moreover, a small excess of sulphuric acid is not

[3] *Journ. de Phys.* 1794, tom. ii. page 231.

injurious, but will rather favour the crystallization of the citric acid, though, perhaps, only inasmuch as it tends more completely to destroy the mucilage.

In opposition to what Crell has observed respecting the crystallization of the citric acid being prevented by the presence of lime, Westrumb says that most of the citric acid, even when crystallized, contains a considerable quantity of lime. However, where this is suspected, it may quickly be known by dissolving some of the crystals in water, and, when the solution has been saturated with ammonia, by treating it with an oxalate of that alkali, which, if there be lime, will immediately separate it in a palpable form.

When the product is laid by for crystallization, it will not be necessary to attend much to the temperature of the room, as I have discovered by experience that the crystals shoot equally well in a warm as in a cold situation.

The crystals thus produced will sometimes, though not generally, be needle-formed; though it has been repeatedly said by the writers on citric acid, that the crystals produced by the first evaporation are *always* needle-formed; but I am inclined to think that this will never be the case if the citrate of lime has been properly freed from the mucilage, and the solution of citric acid not evaporated beyond the due point of concentration, before it be laid aside for crystallization. Indeed, by proper management, I know that perfectly formed rhomboidal crystals may always be procured from the

liquor of the *first* boiling. As the process is usually conducted, these first crystals will be nearly as dark as the brownest sugar. Indeed, every writer on citric acid, whom I have consulted, tells us, that the first crystals will be either dark brown, or black; but I am confident, if the article has not been burnt during the evaporation, that this must be owing to the mucilage not having been sufficiently washed out of the citrate of lime before it is treated with the sulphuric acid; for I have more than once seen crystals of the first crop of a very bright light brown, and even distinct in their form; and such, I conceive, they always will be when the proper precautions have been taken.

Although the crystallized citric acid in any of these states may very well answer most of the purposes to which they are applied by the calico-printer, it is sometimes desirable to have them quite pure; and by dissolving and crystallizing the acid three or four times successively in pure water, very white and beautiful solid crystals of citric acid may at any time be produced; for though the first product may be in needle-shaped crystals, the acid when further purified will always appear in rhomboidal prisms. And if the first solution of the brown crystals be passed through a skin of wash-leather, stretched upon a frame, so much of the colouring matter will be abstracted, that two or three solutions in clear water will be sufficient to give crystals of the desired purity.

The most economical way of conducting this part

of the process is to employ very little more water than is absolutely necessary to dissolve the crystals, and then allow sufficient time for the impurities to subside before the solution is again set apart for crystallization. It would add to the perfection of the crystals, in point of figure, were not only the first but every subsequent solution passed through a clean leathern filter, previously to the acid being allowed to shoot.

There is another point respecting the conducting of this business which deserves our notice, and that is the management of the mother-waters. In the manufacture of every kind of salt, or crystalline acid, the profit very much depends upon the economy which is observed in reducing the mother-waters to a solid and a marketable form. But in this article, the high value of the crystals, and the peculiar difficulties attendant on the reduction of these residuary liquors, render this part of the subject important to those who operate upon a large scale.

Whenever this acid is first boiled to a sufficient strength for crystallization, the small excess of sulphuric acid carbonizes a portion either of the acid or the mucilage; and therefore, when several parcels of lemon-juice have been concentrated, there will at last be a considerable quantity of very black uncrystallizable mother-liquor.

This liquid residuum has given much trouble to some operators, and it has often been thrown away as useless. By the following management, however,

the whole of the citric acid which it contains may be turned to a good account, and produce fair and clean crystals. The process which I would recommend is as follows:

Whatever the quantity of mother-liquor may be, let it be diluted with ten or twelve times its measure of pure water, and the water intimately mixed with it. Then add carbonate of lime to it, by degrees, until it is completely saturated, and proceed with it in all respects as directed at page 543, as if it were fresh lemon-juice.

Here it will be necessary to wash the product of citrate of lime with several successive portions of water; and, if this be attended to, the crop of crystals which it will yield will be as fine as any before obtained.

On referring to the notes which I made in the year 1810, while operating on some large parcels of lime-juice, I find the following entry, which is descriptive of the whole process, and is given in the hope that it may furnish some useful hints to those who have had less practical experience, and enable them to avoid some errors into which I had fallen before I had that knowledge of the process which I have since acquired.

Three casks of lime-juice, which measured together 270 gallons, were drawn off into a large wooden vessel; and to this were added 118lbs of clean carbonate of lime, which completely saturated it. When the citrate of lime had precipitated, the

supernatant liquor was taken away and reserved for another purpose[4]. The precipitate was then carefully washed with hot water from the worm-tub of the laboratory still, and this was drawn off the next morning. The precipitate was afterwards washed several times with cold water; in all seven times, the first washing only being with *hot* water. The water which was drawn off even at the third washing was considerably coloured.

While the citrate of lime was precipitating after the last washing, (and I allowed it due time to subside, in order to separate as much as possible of the water which rested on its surface,) I drew off into another vessel the contents of five pipes more of lime-juice, which in the whole measured 450 gallons. Lime-juice is generally stronger than the juice of lemons, and when it is of the full standard strength it will require half a pound of chalk to every gallon of the juice. Hence it appeared, when too late, that a good price had been paid for a very inferior article;—an inferiority which I imagined was not occasioned by adulteration, but proceeded merely from the natural effects of age. And here it is important to remark, that ordinary juice not only takes less lime, but that sometimes even a

[4] When I reserved this liquor, it was my intention to have separated most of the water, either by evaporation or freezing, and then to have treated the malic acid and the mucilage which would remain with nitric acid, with the view of obtaining oxalic acid, which I thought would be a means of producing some profit, and thus economizing the first process. But I never pursued this object.

considerable portion of what is used does not remain in the vat, but is drawn off with the malic and acetic acids; the malate and the acetate of lime being both soluble salts. Hence the necessity of always employing a chemical test to determine the quantity of sulphuric acid required for the subsequent operation, lest a dependence on the quantity of carbonate of lime used, might mislead. The five pipes of lime-juice above mentioned required 149 pounds of carbonate of lime for its complete saturation.

The precipitate now obtained was treated and washed with the same attention and care as the former, to separate the whole of the malate and acetate of lime, the extractive matter, and the mucilage. Both the precipitates were then removed to a leaden cistern, and 500 pounds of soft water were poured over them, which enabled us very thoroughly to mix the whole.

Two hundred and forty pounds of sulphuric acid of the specific gravity of 1.845 were now diluted with 256 pounds, or 32 gallons wine measure, of soft water, and this diluted sulphuric acid was immediately, whilst hot from the mutual action of the two fluids upon each other, gradually poured in successive portions into the leaden cistern upon the mixture of citrate of lime and water.

While this was doing, two of the workmen never ceased stirring up the whole from the bottom of the cistern, with large and strong wooden spatulas, the more effectually to prevent any part of the

citrate of lime from escaping the action of the sulphuric acid.

Notwithstanding this, I perceived that the precipitate conglomerated very much on every addition of the sulphuric acid;—a circumstance which was occasioned, as I afterwards discovered, by using this acid in too concentrated a state. There is besides another evil attending this; for as sulphuric acid, fully concentrated, will convert the citric into acetic acid, there will always be a danger of lessening the quantity of the produce, when the sulphuric acid is not sufficiently diluted before it is employed. Indeed, from the last operations which I superintended, I am led to believe that it cannot be economical to use this acid in a higher state of concentration than one part of strong sulphuric acid to six parts of water[5].

The whole quantities used were as follow:

Lime-juice	720 gallons.
Carbonate of lime	267 pounds.
Sulphuric acid	240 ditto.
Water, mixed with the sulphuric acid, besides the quantity which was before in the citrate of lime	756 ditto.

It may here be observed, that if the citrate be treated with oil of vitriol *immediately* after it has been washed, as is frequently the case, a dilution of three parts of water to one part of sulphuric acid

[5] More than 20 years ago Lowitz showed the necessity of using a slight excess of sulphuric acid, in order to ensure the obtaining large and regular crystals of citric acid. See Crell's *Annals for* 1799, or *Annales de Chimie* xxxiv. page 181.

may be sufficient, as there will be much water in a state of mixture with the citrate of lime.

Several other parcels of citrate of lime were afterwards treated with sulphuric acid properly diluted, and the several inconveniencies which I have adverted to were avoided; but it is not in my power to furnish the amount of the crystals that were produced from any of these parcels, as I disposed of my share of the whole of the citric acid in a state of solution, and the task of concentrating it for crystallization fell into other hands.

From other experiments, however, I have reason to conclude that 20 gallons of good lemon-juice will generally give 18 pounds of dry citrate of lime, and that if the whole process be well conducted, these 18 pounds of citrate of lime will furnish 10 pounds of good white crystals of citric acid. A well known and highly respectable chemical writer has stated, that "the quantity of solid citric acid in a gallon of lime-juice, varies from 14 to 18 ounces." I confess, however, that I have not been able to procure this proportion from any of the parcels on which I have operated; but there is reason to believe that his experiments were made with lime-juice recently expressed from the fruit.

A different method has been proposed by Richter for procuring the crystallized citric acid; and the author of the process says, that the crystals produced in this way are much finer than those which

are furnished by the old method. It consists in saturating lemon-juice with potash, and in adding to the filtrated solution, a solution of acetate of lead so long as any white precipitate continues to be formed.

In this process the citric acid unites of course to the metal, and the acetic acid with the alkali. The citrate of lead, after being well washed with water to separate any of the acetate which may adhere to it, is to be digested with a sufficient quantity of diluted sulphuric acid, and stirred frequently. During this digestion, sulphate of lead is formed, and the disengaged citric acid exists in the supernatant liquor. By evaporating this with a gentle heat, beautiful crystals of citric acid will be formed.

As the citric acid takes lead directly from the acetous acid, the citrate of lead may be obtained by adding lemon-juice to the acetate of lead. But the mucilage and other impurities are not so completely separated, as when the juice is first saturated with an alkali[6].

I am not able to speak of this process from my own experience; for, knowing that pure and perfect crystals can be procured by the careful management of Scheele's process, I have felt no desire of repeating this of the German chemist, especially as it is more expensive, and the use of lead is objectionable where the crystallized acid is intended for internal and domestic purposes.

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[6] Dr. John Thomson's *Notes on Fourcroy*, vol. iii. page 92.

Fourcroy in his "*General System of Chemical Knowledge*," and in the Lectures which he delivered at Paris, recommended to his fellow-citizens to send proper persons over to their American possessions to collect the vast quantities of limes and lemons which are annually lost there; to saturate the expressed juice with chalk; and to send the washed and dried precipitate, closely packed in barrels, to France, where it might be decomposed, and the citric acid obtained pure[7]. Whether any of the Parisians ever embraced this proposal I have not been able to learn; but I know that some persons have gone from England to different parts of Italy for this purpose, and that considerable quantities of the citrate of lime have been imported from thence into Great Britain.

Having been introduced to a person, who some years ago formed an establishment of this sort in the island of Sicily, I have learned several important circumstances relating to this business, which have never yet been given to the public. I have also been favoured with the perusal of a great part of the correspondence which passed on the occasion; and having obtained leave to print the whole, or any part of these letters, I shall subjoin such extracts as I conceive will be interesting to those who may be desirous of acquiring more information on the subject.

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[7] See Nicholson's *Translation of Fourcroy's System of Chemistry*, vol. vii. pages 277 and 287.

In the first letter, which is dated Messina the 6th September, 1808, this intelligent correspondent says, "The time of pressing is generally in the latter end of the month of November or December, for until that period the lemons yield little or no juice."

"The country round Messina consists of mountains of immense height, rising one above another, and thickly covered to the very tops with fruit-trees, chiefly olives and lemons, which render this place the very best in the world for procuring lemon-juice."

"The quay surpasses most others, extending for a mile and a half, close to the edge of which ships lie in 20 fathom water. Formerly a range of superb houses, perfectly uniform, extended the whole length of this marino, or quay; but ever since the earthquake these magnificent mansions lie in ruins."

"As soon as the country people press the juice, they bring it in here[8] for sale. The buyers do not afford it warehouse-room, but roll it into the street, where it remains exposed to the weather and to the heat of the sun, till an opportunity offers for shipping it. It is therefore not surprising that so much is imported that is musty and perished, and that the English merchants often find it so bad on its arrival in England as to create a difficulty in procuring for it even the amount of the import duty."

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[8] The farmer brings it to Messina in his own casks, and the merchant must provide casks to rack it into when he takes it away.

The fact is, that the juice is laid in by the merchant at Messina in anticipation of a demand; for it is not possible to purchase any goods, whatever may be the species, at the moment you require them. The custom is to pay the sellers, at the time of making the contract, one-third of the amount in advance to enable them to bring their produce to market. You then make further payments in proportion as they send in their goods, till the whole is delivered, and the contract completed.

In one of his letters he remarks, that at this time of the year 200 lemons are generally required to furnish one gallon of juice; and that on this account, there are presses in the island which are so constructed that they will squeeze many thousands of lemons at once.

In a letter dated Messina, Sept. 30, 1808, he says, "The pressing continues till the following March, the quantity of juice produced increasing every month, in proportion as the fruit becomes riper, and the necessity of gathering them greater. The juice is sold by the salm, which is a measure equal to 21 gallons English." In the island of Sicily, oil, wine, brandy, lime-juice, Messina-nuts, and grain, are all sold by the salm; the accounts are kept in onzie of 30 tari, each taro being subdivided into 20 grani. The Sicilian ounce is worth about 10*s*. 2½*d*. sterling, and the taro about 4*d*. Or, more accurately, 1*l*. sterling = 1 ounce 28 tari 15 grani[9].

[9] See Dr. Kelly's *Universal Cambist*, vol. i. page 384.

April 15th, 1809. "I have hitherto found no difficulty in saturating the chalk in any quantity; but the drying is extremely tedious and difficult; it requires very hot and dry weather, which we have had little or none of as yet. I have had parcels lie upwards of a fortnight before they became perfectly dry. When spread out for this purpose, it occupies a vast deal of room, and when the drying-places are all full, I am obliged to stand still, although I have procured the use of a vast terrace belonging to a convent not far distant."

"The citrate, when taken from the baskets in which I drain it, is of a consistence and grain as fine as butter, and so delicate of touch, when about half dry, that if, as on some occasions, when the weather looked uncertain, it became prudent to remove it into the warehouse, to be under cover, it could scarcely be touched without breaking and crumbling into dust."

May 8th, 1809. "I have had many difficulties to contend with in bringing the preparation of the citrate of lime to any perfection; and this chiefly in the drying it, an object of the most material importance; and so much have I been perplexed on this score, that I have felt my expectations quite damped upon the occasion."

"I observed to you before, that the weather had not been settled enough to admit of any attempt at drying out of doors; for the high mountains hanging over us are until the present month continually bringing down showers; and the atmo-

sphere during this time is very unfavourable to drying [10].

"I therefore made use of the upper rooms of my house for this purpose, where I spread out the citrate, and constantly attended to turning it and exposing it to the air for two months: it now appeared perfectly dry, and as hard as in its original state of chalk; and, wanting the rooms to bring forward more, I proceeded to pack it in large casks, to be ready for shipping. However, at the expiration of two or three days, when I began to fill up and cooper the casks, I found the article so heated that I was obliged immediately to turn it all out again to dry it better."

"The cistern in which I work is capable of containing 12 pipes; but notwithstanding the large size of the apparatus, the effervescence occasions me much trouble; and this I attribute to the chalk being sifted to so fine a powder."

"Neither the monks nor any of the inhabitants seem to have the slightest curiosity to know what the article is, although, until it is dry, it continually occasions a most agreeable odour."

In another letter he says, "It is impossible at any price to procure a cistern of wood in this place capable of holding the necessary quantity. There is no wood to be obtained in the island fit for it, and

[10] I have transcribed this and some other passages, merely with the design of moderating the expectations of those sanguine adventurers who may be disposed to embark for this island on a similar business.

much less could a workman be found who would be capable of putting it together. Even baskets for draining must be sent from England, as none but very small ones are to be had in Sicily, and those very poor and slender."

"According to your directions, I have made inquiry respecting the fruit which grows on the coasts of Barbary, and I find there is a considerable quantity of lemons, but they yield very little juice, being of the burgomot species, and have very thick rinds [11].

June 22, 1809. "The storing of lemon juice is here a most difficult and expensive thing, since the soldiers occupy all the places formerly used for this purpose, and also many of the convents [12], which have all very large repositories."

July 4, 1809. "I cannot recollect whether I informed you, but I have been under the necessity of hiring a large room, formerly the refectory of the convent, the door of which opens on the terrace where I dry. This serves also to store the citrate when dry, and at times, when the weather looks

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[11] The Baron Lahontan relates that there are citrons in some parts of Canada, which, instead of a rind, have only a single skin, and that the fruit is as wholesome as the root is dangerous, the juice of the latter being a subtile poison. He proceeds to say that in the year 1684 he saw an Iroquoise woman, who was following her deceased husband, swallow a portion of this juice, which produced instantaneous death. Lahontan's *Voyages to North America*, 8vo, 1735, vol. i. page 250.

[12] Most of these I understand are decayed convents, and a great part of their revenues arises from letting out their large apartments to the merchants and others for storehouses.

squally, to bring it under cover; a very necessary precaution in this climate, as the rain descends in torrents unknown to us in England, and would very soon wash away every thing; so that you see, this business, when conducted on a large scale, requires plans and precautions which nothing but actual operations can point out to us."

"With each shipment I have furnished the real measures of the juice I have used, and the exact quantity of chalk employed in each parcel, from a book which I keep for this purpose; and the measuring, the weighing, and the whole process, have been constantly under my own inspection, for, without my presence, the men will do nothing. This hot country destroys, in a great measure, the energies of mind and body."

June 22, 1810. "I find as much difference in lemon juice as in wine, and both have more or less body, according to the particular soil on which the fruit grows. When fresh squeezed, all seems equally sharp and good. The hot weather, however, is the test, and there is much of the juice we buy which will not bear it; it often changes *very quickly*, and a mawkish vinegar-sort of taste alone remains. Though the early juice resists the heat the best, I can positively assert that, with the utmost care, there is no *certainty* of preserving its native sharpness in the hot months, but by the addition of lime, or some other similar agent."

The following is a tabular view of the quantities of citrate of lime sent from this establishment to

England at each shipment; with the respective quantities of juice and carbonate of lime that were employed in its formation.

Times of Shipment.	Avoirdup. Pounds of Citrate.	Pounds of Chalk employed.	Gallons of Juice employed.	Ounces avoirdup. of Cirate from every Pound of Chalk.		Ounces avoirdup. of Citrate from every Gallon of Juice.	
				Oz.	Drms.	Oz.	Drms.
1809, May 8	3329	2386	4773	22	5½	11	2½
25	2047	1318	2638	24	13½	12	6¾
July 1	6426	3981	8029	25	13¼	12	12⅞
15	3750	2231	4885	26	14	12	4½
1810, June 5	4987	3230	6485	24	11¼	12	4¾
22	8022	5314	10917	24	2	11	12
July 15	7181	5827	13117	19	11½	8	4½
Aug. 22	6798	4930	11098	22	1	9	6¼
	7362	5800	13022	20	4¾	9	0½
	49902	35017	74964				
	Average Produce			22	12¾	10	10¾

On account of the great disproportion which there is in the amount of the different parcels of citrate of lime, produced from their respective parcels of lemon juice, less reliance is to be placed on this table as a perfect document of general reference, than otherwise might be: but as this must have been owing to the operator not being aware of the great difference which there is in the quality of the juice offered for sale, I have taken the pains of throwing the whole of the results into this tabular form, that they may appear at one view, and be a warning to future speculators how they make contracts for lemon juice without submitting the several parcels to previous chemical examination.

As to the disproportion in the quantities of citrate of lime produced from the respective parcels of chalk, and which vary from 20 to nearly 27 ounces for each pound of the earth employed, this must have arisen from his having taken the same quantity of carbonate of lime per gallon for every parcel of lemon juice, as he intimates in one of his letters, than which nothing could have been more improper; as the produce of citrate would sometimes not only be much less than it ought to have been, but, from the earth not being saturated, the article would be of very inferior value.

Dizé, apothecary in chief to the French army, in a paper read before the National Institute of France, says that $6\frac{1}{4}$ pounds of chalk gave him 20 pounds of dry citrate [13]; but this is a quantity which I have never been able to procure, and I conceive he could not have entirely freed the product from the mucilage by washing before he dried it; for this washing must frequently be repeated, or it will not become sufficiently pure. Proust speaks of 30 ounces of dry citrate obtained from one pound of chalk; and this, I am pretty confident, is the most that can be procured [14].

Before I conclude this part of the Essay, it will be right to apprize those who may intend to embark in this business, that it will be necessary to send the carbonate of lime from England, as neither

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[13] Nicholson's 4to *Journal*, vol. ii. page 45.

[14] *Journal de Physique* for 1801, tome lii. page 366.

lime, chalk, nor any other suitable ingredient, is to be found in Sicily.

In sending out whiting or chalk, it will be advisable not to rely entirely on one shipment; for, should only one parcel be sent, and that be lost, it is probable the whole purchase of lemon juice would be spoiled, before a fresh supply of carbonate of lime could be written for, and conveyed to the island.

It should also be known that all the merchants resident in Sicily, have an inveterate jealousy towards any new settlers who may come among them; and therefore strangers will be disappointed if they go with an expectation of receiving the usual accommodations in bill transactions, whatever may be the recommendations which they take out with them. Every article, which is the produce of the island, must be paid for in hard cash, and the purchaser should be provided accordingly.

Considering these, and some other difficulties, which I have already stated, (and I have felt no desire to conceal any circumstance, however unfavourable, which is connected with this subject,) I am inclined to think that by purchasing lemon juice in London or Liverpool, at favourable opportunities, citrate of lime might be made in England nearly as cheap as it could be imported from Sicily, to say nothing of the inconveniencies and disadvantages which must inevitably attend its formation in a distant country. The reader, however, will be able to form his own opinion from the facts which I have detailed.

I am desirous of observing that the juice of several other fruits, besides those of limes and lemons, will furnish the citric acid, either alone or mixed with other vegetable acids. Thus, the cranberry, the *vaccinium oxycoccus* of Linnæus; the red whortle-berry, *vaccinium vitis idæa*; the birds cherry, *prunus padus*, a fruit that is often infused in wine or brandy, to give it an agreeable flavour; the berry of the nightshade, *solanum dulcamara*; and the hep, or fruit of the wild briar, *cynosbatus* vel *rosa canina*, yield chiefly the citric acid[15]: while in the red gooseberry, *ribes grossularia*; in the garden currant, *ribes rubrum*; the bilberry, *vaccinium myrtillus*[16]; the hawthorn, *cratægus aria*[17]; the black cherry, *prunus cerasus*; the wood strawberry, *fragaria vesca*; the knout or cloudberry, *rubus chamæmorus*[18]; and in the raspberry, *rubus idæus*; it is mixed with nearly an equal proportion of malic acid. From all of these the citric acid may however

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[15] Westrumb has shown that the juice of the common cherry contains scarcely any other acid than the citric.

[16] The juice of this berry has been employed to stain paper, or linen, purple. In autumn the moor-game chiefly live upon the product of this shrub.

[17] The wood of the *cratægus aria*, on account of its great toughness, is much used for making wheels and axletrees; it is also so hard and smooth a wood that it is highly esteemed for making the handles of sundry tools used by carpenters and others.

[18] The inhabitants of Norway pack the cloudberry in casks, and send them to the capital of Sweden, where they are served up in desserts. The Laplanders bury them under the snow, and thus preserve them fresh from one year to another. Withering's *Botanical Arrangement*, 8vo, vol. i. Birm. 1776, page 303.

be separated by means of carbonate of lime, if ever a scarcity of limes and lemons should occur.

Simon Pauli has published the method of making a concrete salt from the juice of the barberry; and directions for making barberry-punch of a beautiful red colour are given by Weigleb[19].

It may also be worth mentioning, that sometimes there is a large quantity of damaged tamarinds in the market, which might be bought cheap enough for the use of calico-printers, and which would afford their citric acid to calcareous earth, in the same way as the common lemon juice. Vauquelin, who has made direct experiments upon the tamarind, has shown that one pound of the pulp contains one ounce and a half of solid citric acid[20].

In adverting to the PROPERTIES of the citric acid, its chemical affinities first present themselves to our notice. These, as determined by Bergman, and by Mons. de Breney of the Academy of Sciences at Dijon, are in the following order:

Barytes,	*Oxides of*	Manganese,	Arsenic,
Lime,		Iron,	Mercury,
Magnesia,		Lead,	Antimony,
Potash,		Cobalt,	Silver,
Soda,		Copper,	Gold,
Strontites,		Tellurium,	Platinum.
Ammonia,			

[19] Hobson's *Translation of Weigleb's Chemistry*, 4to, London, 1789, page 178.

[20] Vauquelin's Memoir on the Analysis of the Tamarind will be found in the *Annales de Chimie*, tom. v. page 92.

It is observable, however, that Vauquelin places Magnesia after Potash, Soda and Strontites[21].

When the citric acid is pure and concentrated, it crystallizes in rhomboidal prisms, the sides of which are inclined towards each other at angles of 60 or 120 degrees, terminated at both ends by summits with four faces, which intercept and include the solid angles[22]. Its taste when crystallized is strongly acid and pungent; but when dissolved in water, mild and agreeable. It reddens litmus and other blue vegetable colours. The crystals are soluble in their own weight of water, or according to Vauquelin 75 lbs of water at the temperature of 60° are capable of dissolving 100 pounds of the crystals: boiling water will dissolve twice its weight of them. When the crystals are heated gradually over a fire, the acid becomes dissolved in its own water of crystallization. It undergoes spontaneous decomposition, if long kept in solution, even in close vessels; though lime juice may be preserved good for a long time in glass bottles, if covered with a thin stratum of oil. By concentrated sulphuric acid it is converted to acetic acid; and lastly, the alkaline citrates are precipitated from their solutions by barytic water.

The crystals of citric acid according to Berzelius consist of 100 acid+26.5 water, or 100 parts of

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[21] See Fourcroy, vol. vii. page 287.

[22] Dizé, Nicholson's *Journal*, 4to, vol. ii. page 44.

the pure crystals are composed of 79 acid and 21 water. The same chemist determined[23] that the constituents of the acid are,

Oxygen	54.831
Hydrogen	3.800
Carbon	41.369
	100.000

or

4	proportionals of	oxygen .	$7.5 \times 4 = 30$
3	Do.	of hydrogen	$1.0 \times 3 = 3$
4	Do.	of carbon .	$5.7 \times 4 = 22.8$
			55.8

Professor Brande, however, makes the representative number of citric acid to be 55.5.

The citric was formerly supposed to be identical with the tartaric acid; but they differ in one remarkable particular, viz. that the citric acid does not decompose muriate of potash. It is also readily distinguished from the oxalic acid by its incapacity of decomposing sulphate of lime.

Acetate of lead is decomposed by citric acid, and the citrate of lead that is formed is precipitated in a white powder. The nitrate and acetate of mercury are also decomposed by it; and it imparts a green tinge to the solutions of acetate and sulphate of iron[24].

The SALTS which have been formed by means of the citric acid, being more the objects of curiosity

[23] *Annals of Philosophy*, vol. v. page 93.
[24] Dizé, Nicholson's *Journal*, 4to, vol. ii. page 46.

than of utility, a very brief account of them will be sufficient. They are as follow:

Citrate of AMMONIA.—This salt is formed by dissolving carbonate of ammonia in citric acid. To produce it in crystals, the solution must be evaporated to a thick syrup. Its crystals are elongated prisms, composed, according to Vauquelin, of 62 acid and 38 ammonia[25]. They are very soluble in water.

Citrate of BARYTES is prepared by adding a solution of pure barytes to a solution of citric acid. The salt forms itself into a kind of bush of a silvery whiteness, very brilliant and beautiful; though sometimes it appears in more distinct acicular crystals. It is composed of

Crystallized acid	50
Barytes	50
	100

Citrate of BISMUTH was formed by Vauquelin, and found to be an insoluble white powder.

Citrate of COBALT.—This compound is formed by the union of the oxide of cobalt with citric acid. The product is a soluble salt, whose properties are unknown.

Citrate of COPPER.—Citric acid acts very feebly on metallic copper; but this salt may be formed by boiling the oxide of copper in a solution of citric acid. The concentrated solution, on cooling, yields light green crystals.

[25] Fourcroy's *General System*, vol. vii. page 283.

Citrate of GLUCINA.—This salt may be readily formed, but it does not seem that its properties were examined by Vauquelin when he was engaged in investigating the nature of the other citric salts.

Citrate of IRON has been formed by Vauquelin. When he added iron to citric acid, the effervescence continued four days; the solution was of a brown colour; and by spontaneous evaporation it deposited small crystals of citrate of iron. By concentration, it became black like ink, and ductile like hot resin, but brittle when cold. It tastes very astringent, and is very soluble in water[26].

Citrate of LEAD may be formed by adding a solution of citric acid to a solution of acetate of lead. The salt is in the form of a powder, and is nearly insoluble in water. According to Berzelius, it is formed of

Citric acid	34.5
Oxide of lead	65.5
	100.0

Citrate of LIME.—The formation of this salt has been already described at page 544. When dried, it is in the form of a white powder, nearly tasteless, and scarcely soluble in water. It is soluble, however, in its own acid, which accounts for the concentrated acid generally containing a portion of lime. It is a compound of

Lime	33
Citric acid	67
	100

[26] Fourcroy's *System of Chemistry*, vii. 284.

Or it may be said to consist of

1 proportional of acid	=	55.5
1 ditto of lime	=	26.5
		82.0

Citrate of MAGNESIA is readily formed by dissolving carbonate of magnesia in citric acid. It does not crystallize, but forms, according to Vauquelin, a white mass which rises in the vessel like a mushroom [27]. According to this chemist, it is composed of

Citric acid	66.66
Magnesia	33.34
	100.00

Citrate of MANGANESE.—Citric acid dissolves the black oxide of manganese, and produces, according to Professor Brande, white arborescent crystals [28].

Citrate of MERCURY. Citric acid will not dissolve metallic mercury; but with the red oxide it forms an insoluble white mass. A proto-citrate and a per-citrate may be formed with this metal; but they are both insoluble salts [29].

Citrate of POTASH.—To form this salt, nothing more is necessary than to dissolve carbonate of potash in citric acid, and concentrate the solution by evaporation. It is extremely soluble, and crystallizes with difficulty. It was called the salt of *Riverius* in the old Pharmacopœias, and is still much used in medicine. It is deliquescent and decom-

[27] Fourcroy's *System of Chemistry*, vol. vii. p. 283.
[28] *Manual of Chemistry*, vol. iii. page 95.
[29] Fourcroy's *System of Chemistry*, vol. vii. page 285.

posable by barytes and lime[30]. Vauquelin, who paid considerable attention to this salt, found it to consist of

Citric acid	55.55
Potash	44.45
	100.00

Citrate of SILVER.—Silver is not acted upon by citric acid; it dissolves its oxide, however, and forms with it a salt in the form of a white powder, which has a harsh styptic taste, and is insoluble in water. Though white when it is first formed, it becomes, like other salts of silver, black by exposure to the light[31]. It is a compound of

Citric acid	36
Oxide of silver	64
	100

Citrate of SODA.—This salt is formed by dissolving soda or its carbonate in citric acid. It has a faint and saline taste, and is difficultly crystallizable; but when crystallized, it requires nearly two parts of water for its solution. It crystallizes in six-sided prisms, or in hexahedral tables[32]. It consists of

Citric acid	60.7
Soda	39.3
	100.0

Citrate of STRONTITES was formed by Vauquelin

[30] Fourcroy's *System of Chemistry*, vol. vii. page 282.
[31] *Id. Ibid.* page 285.
[32] *Id. Ibid.* page 283.

by the mixture of citrate of ammonia with nitrate of strontites. It is a crystallizable salt, and soluble in water.

Citrate of URANIUM has been formed by digesting oxide of uranium in citric acid. The salt crystallizes with difficulty, but it is soluble in water.

Citrate of ZINC.—Citric acid acts freely on metallic zinc or its oxide. Small brilliant crystals of citrate of zinc are formed which have a strong metallic taste, but they are scarcely soluble in water[33]. The salt is a compound of

Citric acid	59
Oxide of zinc	41
	100

It would be improper to dismiss this subject, without adverting to the application and general USES of the citric acid.

Besides the common medicinal[34] purposes to which the citric acid is applied, such as the making of saline draughts, &c., it is often combined with opium to prevent the stupifying effects of that very powerful narcotic; and I have been told that it has been given with good effect to counteract such an over-dose of it as would otherwise have proved fatal.

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[33] Fourcroy's *System of Chemistry*, vii. 284.

[34] Speaking of the medicinal uses, reminds me of what I have read respecting the effect of citric acid on milk. It is said that although it curdles the milk of most animals, it has not this effect upon human milk, whether used hot or cold. Voltelen *Obs. Chem. Med. de Lacte humano.* Traj. Batav. 1775.

Its operation in obviating the destructive power of this or some other powerful drug, was known to the ancients; for it is evidently alluded to in Virgil's *Georgics*, as may be seen in the Appendix [35].

In domestic economy the citric acid is employed with advantage as a condiment for a variety of food, it being more grateful than vinegar on account of the fine aroma derived from the essential oil peculiar to the rind of the fruits which produce it. Likewise for taking out iron-moulds or other stains of iron; as this metal is not only soluble in citric acid, but the solution is so permanent that it is not precipitated again by the application of soap, which sometimes happens when other salts are used for this purpose. It is useful also for removing spots occasioned by alkalies, or the alkaline earths, from scarlet cloth;—for making a solution of iron for bookbinders, to give the mottled appearance to the surface of calf-skin;—for improving that peculiar solution of tin which is employed for producing the most exquisite specimens of the scarlet dye;—for altering the hue of some colours which are exclusively used in the dyeing of silk;—for the preparation of the best Morocco leather;—and for improving candles, by whitening and hardening the tallow which is employed in making them.

A very considerable quantity of citric acid, in the form of lemon juice, is also consumed by the seamen of the British navy[36]. It was formerly bought in

[35] See also Girtanner in *Annales de Chimie*, tom. 34, p. 306.
[36] Lord Anson and Captain Cook were the first navigators

London, having first been submitted to the judgement of a respectable chemist, who was regularly employed for the purpose. As the managers of this department have found that it can be brought from Sicily at a much more reasonable price, and of the best quality, they now procure it from that island, and decline all other sources. To preserve it on long voyages, they generally put about 10 gallons of brandy to every 100 gallons of the juice, which has the effect of precipitating the mucilage, that otherwise would not fail, during an extended voyage, to throw the whole into a state of fermentation, and convert much of it into vinegar.

Dizé, in his memoir already mentioned [37], says that a lemonade of the most agreeable taste and appearance may be made by dissolving 40 grains of citric acid in a pint of water, with the addition of a sufficient quantity of refined sugar, and that it may be rendered fragrant by dissolving in it a small quantity of oleo-saccharum, prepared by rubbing a lemon on a lump of sugar. The sugar, by imbibing the volatile oil of the lemon, renders it perfectly soluble. By this means it is easy to preserve the volatile oil of any number of lemons. The oleo-saccharum thus obtained may be mixed in a mortar with a sufficient quantity of sugar; and when this has been dried by a very gentle heat, it may be kept in well stopped bottles unimpaired for any length of

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who employed lemon juice on their ships' crew for the prevention and cure of the sea-scurvy.

[37] Nicholson's 4to *Journal*, vol. ii. page 45.

time. This is preferable to the volatile oil of lemons obtained by distillation, because the fire often imparts an unpleasant or empyreumatic flavour to it.

Other domestic and economical purposes might be enumerated, to which citric acid is applicable, especially now that it can be kept in its crystallized state in every family, in which form it is liable neither to decay nor even to the slightest alteration.

An aceto-citric acid has been much employed in various processes of dyeing by Mr. Guhliche. He calls it vegetable acid spirit, and prepares it in the following manner:

He takes any quantity of lemons (those of which the rind is decayed will do); he removes the peel and the skin that adheres to it, and slices them into a vessel, which ought not to be made of wood. He then sprinkles them with a quantity of good vinegar; squeezes out the juice through a flannel, by means of a press, and filtrates the expressed liquor through paper. It may be used in this state; but as it is apt to grow mouldy, he directs it to be purified and concentrated as follows:

The liquor is to be exposed to the sun, until it forms a sediment, and the upper part grows clear. It is then to be filtrated, and distilled in a sand bath. The receiver is to be changed when the liquor that drops becomes acid, and the distillation continued until oily streaks are perceptible in the neck of the retort. The acid now found in the receiver, is to be preserved for use[38].

[38] For an account of the way in which Mr. Guhliche uses this

Citric acid is principally consumed by the calico-printer, who uses it in several processes of his art, especially to discharge iron, and to preserve white grounds on certain parts of a pattern, by means of the property it has of resisting the operation of sundry dyes, as is more fully explained in the Essay on Calico-printing.

The person who first prepared this acid in large quantities in England, and chiefly for the use of the calico-printers, was Mr. Coxwell, late of Fleet-street, who sold it at a high price in the form of clean white crystals. With this the printers were supplied for many years; but when the demand became greater than he could well answer, he began to furnish them with the brown crystals, that is, with the acid in the first or second stage of crystallization, and consequently at a much lower price.

The discovery that citric acid can be used in a brown state for calico-printing occasioned the printers pretty generally to turn their attention to the preparation of the citric acid; and now most of the proprietors of the large establishments buy lemon juice for themselves, and use it in different states of concentration, according to the nature of the processes to which it is to be adapted.

For most of the styles of work in which citric acid is employed, they find that the common impurities in lemon juice are of very little consequence; and

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aceto-citric acid, I must refer the practical dyer to Mons. Berthollet's *Elements of the Art of Dyeing*, by Hamilton, London, 1791, vol. ii. page 244.

that when the juice itself has undergone no other process than that of being concentrated by the evaporation of a portion of the water it contains, it very well answers their purpose, and supersedes the use of the crystallized acid.

As there is always abundance of spare heat in every large calico-print work, the process of evaporation may be conducted at no expense: and if it be continued very slowly for some considerable time, the acid will be sufficiently concentrated, and this without waste. For when the evaporation is thus managed, the vapour which arises will carry off none of the acid; and when it arrives at a certain point of concentration most of the mucilage will be separated, one part of which generally rises to the surface, and the other precipitates.

It is time, however, to come to the particular point which first induced me to think of writing on this subject, namely the knowledge of the circumstance, that the printers depend solely on the hydrometer for ascertaining the goodness of lemon juice. This made me very desirous of recommending to them some less fallacious guide.

Various reasons may be adduced to show the uncertainty of the hydrometer; but one or two will suffice. It is possible, for instance, that two parcels of juice may appear to differ very much, when examined by the hydrometrical test, from the difference of the quantity of mucilage, though the same parcels may be of equal goodness as to the produce of the crystals or real acid that may be pro-

cured from them. In like manner, a pipe of lemon juice may be sophisticated with other acids, so as to make it pass the hydrometer, and yet be worth little for the printer's use.

On these accounts it appears to me that there can be no safety in purchasing this article, unless the buyer avail himself of the use of chemical tests, especially as an experienced calico-printer has assured me that fine wheat flour is sometimes employed to adulterate lemon juice. It certainly may be so incorporated with the mucilage as to affect the hydrometer considerably.

Whenever, therefore, a parcel of lemon juice is offered for sale, the first thing should be to take its specific gravity by the hydrometer, or by means of a specific-gravity bottle, and note that down. Should it prove to be only of the specific gravity of about 1.0156, which is 16 ounces 4 drachms to the wine pint, it may at once be rejected as not worth purchasing; for good juice varies from a specific gravity of 1.0312 (16 ounces 8 drachms) to that of 1.0625, or 17 ounces avoirdupois the wine pint[39].

Should the parcel appear good by the hydrometer, take then, for the next experiment, a wine glass of the juice, dilute it plentifully with pure water,

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[39] When the wine pint is mentioned in these volumes, a measure is intended that holds exactly 16 ounces avoirdupois of pure water; and such measure is referred to here and elsewhere, because it is a measure very generally understood by manufacturers, and accommodates those persons who are unable to calculate by the specific gravity as usually denoted in books of chemistry.

and add to it a few drops of a solution of acetate of lead as directed at page 548: this will produce an immediate precipitate, chiefly of citrate of lead, which should then be treated with a little pure nitrous acid, and the effect carefully observed; for, if the nitrous acid dissolve the whole of the precipitate, it will prove that the juice under examination contains no sulphuric acid. By proceeding in the same way with an acidulous solution of nitrate of silver[40], instead of acetate of lead, it will be seen whether the juice contains any muriatic acid; this and the sulphuric being the only two acids, except the acetic, that are ever likely to be employed in the adulteration of lemon juice.

There were indeed instances, when lemon juice was scarce in the market, of its being adulterated with vinegar; and should this occur again, it may be readily detected by saturating a sample of the juice with carbonate of lime (whiting or pure chalk), and when the calcareous citrate precipitates, taking the specific gravity of the supernatant liquor. For, as lime is entirely soluble in acetic acid, part of the whiting employed will be held in solution by the vinegar, and occasion the supernatant liquor to be

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[40] To prepare the nitrate of silver, dissolve a drachm of lunar caustic, which may be procured from any respectable apothecary, in one ounce of soft water, and to this add half an ounce of strong nitrous acid previously diluted with an equal portion of water. When the impurities have precipitated, pour off the clear supernatant liquor, and preserve it in a stoppered phial for use.

specifically heavier than it would have been had the sophistication not been practised.

To render this fact more certain, I made the following experiment. Having purchased a few good lemons, and pressed out the juice, I found its specific gravity to be 1.0384. This was put into a capacious phial, and when loosely corked was placed in a secure place the temperature of which was usually at about 60 degrees. When it was examined at the end of sixteen days, the mucilage had in a great measure deposited, and the specific gravity of the juice was found reduced to that of 1.0352.

The weight of the juice under experiment, and after it had passed the filter, was 2400 grains, and the deposited mucilage weighed 133 grains, or one-nineteenth of the whole.

The clear juice being divided into two equal portions, to one of them a fourth of its weight of common vinegar was added. Finding that the unadulterated portion amounted to 1200 grains, an equal quantity was taken of that which contained vinegar mixed with it, and both these parcels were accurately saturated with carbonate of lime[41], and left 24 hours undisturbed until the citrate of lime thus composed should be deposited.

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[41] The 1200 grains of pure lemon juice required 98 grains of carbonate of lime, whereas the same weight of acid previously sophisticated with vinegar took 102 grains for its complete saturation.

On pouring off the supernatant liquors from the two parcels of calcareous citrate, and drying both their precipitates equally, the following results presented themselves. The citrate of lime from the pure juice, when perfectly dried, weighed 138 grains, while that from the adulterated parcel weighed only 129 grains. The specific gravity of the supernatant liquor from the former was 1.0076, or 16 ounces and 2 drachms to the wine pint; but that from the latter, in consequence of the lime taken up by the vinegar, was 1.0135, or 16 ounces and 3 drachms and a half to the pint. By a similar experiment, the adulteration of lemon juice with vinegar may at any time inevitably be detected.

When it has thus been found that a sample of lemon juice contains no admixture of other acids, the next step ought to be to ascertain how much real citric acid any given quantity of such juice actually holds in solution. For though it may not have been designedly sophisticated by any extraneous matters, it may be very inferior from other causes, the extent of which can only be accurately discovered by the application of another chemical test.

For instance, the fruit of which it was made may have been gathered in an unfavourable month, after the descent of the heavy rains; or deteriorated by the spontaneous decomposition which is occasioned by age; or it may have been diluted with water; all of which may be apprehended, when it is not known how many hands the juice has passed

through before it comes into the possession of the consumer.

The mode which naturally suggests itself of ascertaining this point, is by means of an alkali; for if it be proved by the foregoing tests that the juice contains no admixture of other acids, the amount of the crystals of citric acid which it will yield will be in exact proportion to the quantity of alkali which it requires for its saturation.

To adapt this theory to practice, all that is necessary is to select some alkali, such as pearl-ash, or the crystals of soda, of which a solution is to be made, something below the point of saturation; and when this has been filtrated through blotting-paper, and its specific gravity noted down, it will be ready for use, and should be carefully laid by, to have recourse to whenever occasion requires.

It will be necessary also to procure some of the test-paper which is generally used for acids and alkalies. For this purpose, I know of none better than the common blue litmus paper, which may be bought in London by the sheet. This paper should be kept in a stoppered bottle, or closely folded in paper, to preserve it from the action of the atmosphere, as well as from the light, and this will always prove an excellent test to discover the presence of an acid, which instantly changes the blue to a red; and the same paper, being slightly tinged by means of a very dilute acid, becomes equally delicate as a test for alkalies. A very *weak* mixture of vinegar and water answers this purpose.

The use which the calico-printer will have to make of these papers, is to ascertain when the portion of lemon juice under examination is exactly saturated with the alkali. He may, therefore, proceed with it in the following manner:

Let one thousand grains, or any given quantity, of the lemon juice be weighed out; and having previously balanced a phial of the solution of alkali in an accurate pair of scales, let a portion of the alkali be gradually added to the juice, which should be well stirred with a glass rod, or poured from one vessel to another, between every addition of the alkali. When the effervescence seems to grow less and less, a slip of the blue test-paper should be dipped in to ascertain whether the mixture approaches the point of saturation. If the paper comes out red, it indicates that the acid still predominates, and more alkali must therefore be cautiously dropped in. After waiting a minute or two, to allow time for them to unite, another slip of test-paper is to be applied, and in this way repeated until the liquor has lost the power of occasioning any change in the colour of the test.

When this is the case, a slip of the *reddened* test-paper should be dipped in, which will acquire a blue colour if too much of the alkali has been used; but if the liquor be brought to that state that it will cause no visible change of colour in either the red or the blue litmus paper, the lemon juice may then be considered to be accurately saturated, and brought to the neutral state.

Now, replace the phial of dilute alkali in the scale, note down how many grains in weight are requisite to balance it, and call this the quantity of alkali expended in saturating the juice. When the operator has by previous experiment determined how much of his standard alkali is necessary to saturate any given quantity of the pure crystals of citric acid, he may at once, by the common rule of proportion, find how much solid citric acid is contained in any particular sample of lemon juice, which has been submitted to the tests already described.

The method now recommended of examining the goodness of lemon juice, will answer the purpose of any individual so far as respects his own purchases; but as the pearl-ash of commerce contains different proportions of impurity, and the crystals of soda are liable to effloresce, and thence to hold variable quantities of the water of crystallization, neither of these is fit for forming a standard by which both the buyer and the seller may arrive at the same estimate of the value of any given parcel of juice.

Conceiving, however, that this would be a very desirable thing to accomplish, I have thought of various expedients, and know of nothing which would be so generally convenient for effecting this purpose as the common salt of tartar of the shops, which, if bought of a respectable chemist, will be found to be a tolerably pure carbonate of potash; and if this be preserved in a well-stoppered bottle

from the action of moisture, it will be a useful test for the purpose under consideration.

In order to lay the foundation for a table of the quantities of pure alkali which are taken up by this acid in various states of concentration, I prepared some of this carbonate of potash, and found that 544 grains of such alkali are required to saturate one ounce avoirdupois, or 437.5 grains of pure dry solid crystals of citric acid; or, that one ounce and a quarter, omitting fractions, will render neutral one ounce of the crystallized citric acid. When this fact was ascertained, a foundation was laid for the construction of the Table No. I.

Conceiving, however, that, for the purposes of business, a solution of potash in pure water might be more generally useful than the dry salt of tartar, I formed an aqueous solution of that alkali, somewhat below the point of complete saturation, by dissolving two ounces and a half of the salt of tartar in thirteen ounces and a half of pure water, making in the whole one pound avoirdupois; and by means of this solution the table No. III. in this Essay, has been constructed.

These proportions of water and alkali were chosen, in order that the solution might be of such a strength that eight ounces of it would accurately saturate as much lime juice as should contain one ounce of pure solid crystals of citric acid. The specific gravity of such a solution at 60°, when filtrated, will be 1.120, or 17 oz. 12$\frac{3}{4}$ drachms to the wine pint.

Notwithstanding the general certainty that must result from this mode of procuring the test, it occurred to me that it would be more convenient to some calico-printers to use soda. I therefore prepared some crystals of this alkali in a state of purity; and having carefully abstracted the water of crystallization, I found that 352 grains of this dry subcarbonate of soda will accurately saturate an avoirdupois ounce of the pure crystals of the acid of lemons; and on this result has the table been formed which is marked No. III.

In order to separate the water of crystallization entirely, so as to procure a perfectly dry and impalpable powder of carbonate of soda, it is necessary to expose the crystals to a very gentle and long continued heat; for when dried hastily, the pulverized crystals will be apt to melt in their own water of crystallization, and become reconverted into a hard mass.

It is worthy of notice, that these tests may be employed, not only in purchasing lime juice, but also in ascertaining the quantity of real acid in acid liquors of different degrees of concentration; a matter of considerable consequence to those printers who are desirous of being accurate in the proportion of acid which they employ in any particular style of work.

As some of the calico-printers in the North of England have found it advantageous to buy lemon juice instead of citric acid, and use it, after it is concentrated by evaporation, without further purification, as mentioned at page 584, I would here

take the opportunity of suggesting, that when the juice has been partially concentrated by being exposed for some time to a very moderate heat, it would be useful to remove it to a situation where the evaporation will be suspended, and where it can remain undisturbed for a day or two, to give time for the thickened mucilage[42] entirely to subside. It will then be advisable to draw the fluid from the precipitated impurities, by a syphon, or other means, and to pass it through a filter, before it be submitted to any further process of concentration.

If it be treated in this manner, I am of opinion that it may not only be sufficiently concentrated, but that it will also be sufficiently pure, for almost every purpose to which the calico-printer can possibly have occasion to apply it.

However, should the printer be desirous of purifying his lime juice by the chalk process as described at page 543, &., I see no reason why he may not afterwards evaporate the fluid by some such method as is directed above, and use it in any stage of its concentration that may be most suitable, without being at the expense of reducing it to the solid form.

To render this more easy, I have constructed a

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[42] Fourcroy, who has examined this precipitate, says, that "it is not a simple vegetable mucilage, but has some analogy with gluten; for that when dried, it is not soluble in boiling water; that if treated by nitric acid, it yields azotic gas, and is converted into malic and oxalic acids." Fourcroy's *System of Chemistry*, vol. vii. page 274.

table of the quantities of purified acid in a given portion of liquor of different strengths, as indicated by their specific gravity: and another table of a similar nature for the unfinished acid, or brown crystals [43], which I presume will be used with more propriety than the former, whenever it is necessary to ascertain the quantity of acid in the liquor of the first boiling. Both these tables will be found in the subsequent pages marked No. IV. and V.

Having thus given a detail of every thing of importance which has occurred to me respecting this subject, I have only to add, that I shall be much obliged to any calico-printer or other person who shall have made observations that have escaped my notice, if they will favour me with the results of their experience. Of these I shall most gladly avail myself in a future edition of these volumes; being anxious to omit nothing that can be worth the notice of those who by curiosity or interest may be induced to investigate the nature of this singular and very useful acid.

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[43] It will be perceived, that the specific gravity of the solution of brown crystals is greater than that of the pure crystals. This I apprehend arises from the brown crystals generally retaining a portion of sulphuric acid.

TABLES.

No. I.

Table of the Quantity of pure Crystals of Citric Acid which may be obtained from different Parcels of Lime or Lemon Juice, as indicated by the Proportions of DRY *Salt of Tartar* required for their Saturation.

Quantity of Juice saturated by the Test.	Quantity of dry Salt of Tartar employed.	Quantity of Crystals of Citric Acid which may be obtained from one Gall. of such Juice.
	Grains.	Ounces avoirdupois.
1 Ounce Measure of Lemon Juice *.	4¼	1
	8½	2
	17	4
	21¼	5
	25½	6
	29¾	7
	34	8
	38¼	9
	42½	10
	46¾	11
	51	12
	55¼	13
	59½	14
	63¾	15
	68	16

* The method by which this Table was constructed has been already explained at page 593; but it may be further observed, that the ounce measure here intended, is one-sixteenth part of the wine-pint, or the one hundred and twenty-eighth part of the wine-gallon.

No. II.

A Table of the Quantity of pure Crystals of Citric Acid which may be obtained from different Parcels of Lime or Lemon Juice, as indicated by the Proportions of the SOLUTION of *Salt of Tartar* required for their Saturation.

Quantity of Juice saturated by the Test.	Quantity by Weight Avoirdupois of the Solution employed.	Quantity of Crystals of Citric Acid which may be obtained from one Gall. of such Juice.	
	Drachms.	Ounces.	Drachms.
1 Ounce Measure of Lemon Juice.	4	4	0
	4½	4	8
	5	5	0
	5½	5	8
	6	6	0
	6½	6	8
	7	7	0
	7½	7	8
	8	8	0

To avoid extending this Table, it may be remarked, that the solution of carbonate of potash has been contrived to be of such a strength, that whatever number of avoirdupois *drachms* of it may be required to saturate the acid in one ounce measure of lemon juice, the same number of *ounces* of pure rhomboid crystals of citric acid may be obtained from every gallon, wine measure, of a similar juice. For the principle on which this Table is constructed see page 593.

No. III.

A Table of the Quantity of pure Crystals of Citric Acid which may be obtained from different Parcels of Lemon Juice, as indicated by the Quantity of DRY *Carbonate of Soda* required for its Saturation.

Quantity of Juice saturated by the Test.	Number of Grains of the dried Carbonate of Soda employed.	Quantity of Crystals of Citric Acid which may be obtained from one Gall. of such Juice.
	Grains.	Ounces Avoirdupois.
1 Ounce Measure of Lemon Juice.	11	4
	13¼	5
	16½	6
	19¼	7
	22	8
	24¾	9
	27½	10
	30¼	11
	33	12
	35¾	13
	38½	14
	41¼	15
	44	16

To prevent the possibility of any misconception respecting the nature of these Tables, it may be proper to state an example of the use of each. For instance, if it be required to examine a parcel of lemon juice by the *dry* salt of tartar, all that is necessary is to take an ounce measure [44], or the sixteenth part of a wine-pint of such juice, and having noted the number of grains required for its sa-

[44] These measures may be bought in London, at Messrs. Knight's in Foster-lane, or of Mr. Newman in Lisle-street.

turation, to look for the same number in the second column of the first Table; and opposite thereto, in the third column, will be seen the quantity of crystals of citric acid which may be obtained from a gallon of such juice. The Table No. II. is constructed in the same manner, for the use of *a solution* of salt of tartar to be prepared as directed at page 593. The Table No. III. is contrived in a similar way for the use of the carbonate of soda to be dried in the manner prescribed at page 594.

No. IV.

A Table of the Solution of WHITE Crystals of Citric Acid.

Crystallized Acid.	Ounce Measures of Water.	Sp. Grav. at the Temp. 55 Degrees.	Avoirdupois Weight of the Wine-pint.		Quantity of Crystals dissolved by one Gallon of Water.		
	Oz.		Oz.	Dms.	lbs.	Oz.	Dms.
1 Ounce Avoirdupois.	1	1.2187	19	8	8	0	0
	2	1.1395	18	3¼	4	0	0
	3	1.1016	17	10	2	10	10½
	4	1.0799	17	4½	2	0	0
	5	1.0663	17	1	1	9	9½
	6	1.0575	16	14¼	1	5	5½
	7	1.0494	16	12½	1	2	4½
	8	1.0433	16	11	1	0	0
	10	1.0352	16	9		12	12¼
	12	1.0298	16	7½		10	10½
	14	1.0250	16	6½		9	2½
	16	1.0216	16	5½		8	0
	20	1.0162	16	4¼		6	6½
	24	1.0135	16	3½		5	5½
	28	1.0115	16	3		4	9½
	32	1.0101	16	2½		4	0

As some calico-printers are in the habit of measuring their iron liquor and other mordants by the

ale-gallon, which is more than a fifth larger than the wine-gallon, it is necessary to inform such persons that these Tables are all calculated for wine-measure, which is a vessel holding exactly eight pounds of distilled water.

No. V.

A Table of the Solution of BROWN Crystals of Citric Acid.

Crystallized Acid.	Ounce Measures of Water.	Sp. Grav. at the Temp. 55 Degrees.	Avoirdupois Weight of the Wine-pint.		Quantity of Crystals dissolved by one Gallon of Water.		
	Oz.		Oz.	Dms.	lbs.	Oz.	Dms.
1 Ounce Avoirdupois.	1	1.2656	20	4	8	0	0
	2	1.1640	18	10	4	0	0
	3	1.1171	17	14	2	10	10½
	4	1.0937	17	8	2	0	0
	5	1.0820	17	5	1	9	9½
	6	1.0664	17	1	1	5	5½
	7	1.0566	16	14½	1	2	4½
	8	1.0526	16	13½	1	0	0
	9	1.0488	16	12½		14	3½
	10	1.0448	16	11½		12	12½
	12	1.0390	16	10		10	10½
	14	1.0332	16	8½		9	2½
	16	1.0312	16	8		8	0
	18	1.0273	16	7		7	1½
	20	1.0254	16	6½		6	6½
	24	1.0214	16	5½		5	5½
	28	1.0195	16	5		4	9½
	32	1.0156	16	4		4	0

The Tables Nos. IV. and V. are founded on actual experiments, undertaken for the purpose of ascertaining the specific gravities of the solutions of this acid at different degrees of concentration. A single example will be sufficient to explain their design.

Suppose a printer, who uses purified crystals of citric acid, should find that a solution of the specific gravity of 1.0162 is suitable for any particular purpose, he will learn, by reference to the Table No. IV., that he may prepare a similar solution by dissolving one ounce of crystals in 20 ounces of water, or 6 ounces 6¼ drachms in one gallon of water. The Table No. V. is constructed upon the same principle, and is intended for the use of those printers who employ the brown crystals.

APPENDIX.

ADDITIONAL NOTES

TO

THE FIRST VOLUME.

NOTES TO ESSAY I.

1. *The mariner's compass.* Page 3, line 6.

SINCE this Essay was written I have been convinced that Flavio Gioia could not have been the inventor of the mariner's compass, though it has generally been attributed to him; because Hugh de Berry, a French poet, who wrote in the beginning of the 13th century, plainly refers to it, and says that "sailors employ a needle which has been rubbed on a loadstone, and that this small instrument is fixed on a board which floats in a vessel of water."—Pasquier, *Recherches de la France*, liv. 4. c. 25, page 405. Anderson says that Gioia discovered the compass in 1302: but this cannot be correct, as the poem above referred to was written half a century before this period. It is probable, however, that the mariner's compass had been in use before Flavio Gioia was born, and that he improved its construction. This appears likely, from the circumstance of Principato, in the kingdom of Naples, (the place of his nativity,) bearing a compass for its arms; and it has been said that as Gioia was a Neapolitan, and as the sovereigns of Naples in his time were branches of the royal family of France, he, in order to mark the circumstance of the invention originating with a subject of Naples, distinguished the North by a *fleur de lis*. Anderson's *History of Commerce*, vol. i. page 144. *Biog. Dictionary*, vol. vii. page 24.

About the middle of the 17th century, a native loadstone was dug up in Devonshire of the enormous weight of sixty pounds. Its magnetic power was so great that it would move a needle at nine feet distance. Dr. Cotton made a present of it to the Royal Society. *Philosophical Transactions*, vol. ii. *for the year* 1667, page 423.

2. *Invention of printing.*—Page 3, line 8.

"We have a fact established beyond controversy, that WILLIAM CAXTON, an eminent mercer and negotiator, first introduced the art of printing with *fusible* types into England; and some suppose that Frederic Corsellis, or some other foreigner, used *wooden* types a few years before him. He was succeeded by Wynkyn de Worde, who improved the art very much, and first introduced musical notes, and (some think) Roman numerals: but the Roman character was first used in printing by Pynson, who was by extraction a Norman. The progress of the typographic art among us was very rapid. Margaret, Duchess of Somerset, or more properly Countess of Richmond and Derby, took it under her patronage, and Pynson had a formal appointment of the office of king's printer, in the beginning of the reign of her grandson Henry VIII."—Herbert's *Preface to Ames's Typographical Antiquities.* The first book known to be printed in England was by Caxton in the year 1474. The first by his successor, Wynkyn de Worde, appeared in 1494.

3. *The alchemists.*—Page 4, line 6.

The following proclamation respecting two noted alchemists was published by King Edward III. A.D. 1329. "Know all men, that we have been assured, that John Rows and Mr. William de Dalby know how to make silver by the art of alchymy; that they have made it in former times, and still continue to make it; and considering that these men by their art, and by making that precious metal, may be profitable to us, and to our kingdom, we have commanded our well-beloved Thomas Cary to apprehend the foresaid John and William wherever they can be found, within liberties or without, and bring them to us, together with all the instruments of their art, under safe and sure custody."—Rymeri *Fœdera*, tom. iv. page 384.

So lately as the year 1784, Dr. James Price, F.R.S. of London, attempted to revive the spirit of alchemy. He produced a red and a white powder, with which he boasted that he could convert mercury into gold or silver. He made several experiments before a number of respectable persons; but when the powders were exhausted, and he was importuned on all sides to renew his powders and repeat his experiments, before men of science, he swallowed laurel water and put an end to his existence.—Crell's *Chemical Annals*, 1784.

4. *Lord Bacon.*—Page 4, line 9.

This great and eminent man, who is generally acknowledged to have been the father and founder of rational experimental philosophy, is deserving of distinguished notice in every modern

work that professes to treat of the origin and progress of the sciences, especially that of chemistry. David Mallet, who wrote the life of this great philosopher, has left us the following testimony in his favour.

"Nothing," says he, "can give a more exalted idea of the fruitfulness and vigour of his genius, than the number and nature of his writings. These are not works of mere erudition and labour, that require little else but strength of constitution and obstinate application; they are original efforts of genius and reflection, on subjects either new, or handled in a manner that makes them so. To this commendation of his talents, the learned throughout Europe have given their common sanction, and own him for the father of the only valuable philosophy—that of fact and observation."

"From an examination of his great work, entitled 'The Instauration of the Sciences,' it appears that he was not only well acquainted with every thing that had been discovered in books before his time, and able to pronounce critically on those discoveries, but he saw clearly, and at the end of this Treatise has marked out in one general chart the several tracts of science that lay still neglected or unknown. And to say the truth, some of the most valuable improvements since made, have grown out of the hints and notices scattered through this work: from which the moderns have selected, each according to his fancy, one or more plants to cultivate and bring to perfection."

"France, Italy, Germany, Britain, I may add even Russia, have taken him for their leader, and submitted to be governed by his institutions. The empire he has erected in the learned world is as universal as the free use of reason: and one must continue till the other is no more."—David Mallet's *Life of Lord Bacon*, prefixed to his Works in 5 vols. 4to, London, 1778.

5. *Geber.*—Page 5, Note 2.

John Geber was a man of great acquirements. A list of his writings will be found in the *Biographical Dictionary*. His chemical works were first published in English at Leyden, in the year 1668, by Richard Russel, who ten years afterwards reprinted them in London in a small duodecimo volume.

6. *Irrigation.*—Page 9, Note 7.

The agriculturists of the present day whom I have heard of as being the most successful in this practice, are Mr. Pagett of Ibstock in the county of Leicester, the late Mr. Wilks of Overseal, Mr. Bakewell, Mr. Templar of Stover, Mr. W. Smith, and the Rev. Theophilus Houlbrooke of Shropshire. Many others might doubtless be added. See the Essay on WATER in the second volume.

7. *Magnesian limestone.*—Page 10, line 3.

When this paragraph was written, I was not aware that some well-informed agriculturists entertain a different opinion. It is asserted by them that lime and magnesia are both hurtful when employed in improper situations, or in excessive quantity, but that magnesia in itself is not essentially injurious. See *The Elements of Agriculture,* by John Naismith, author of the General View of the Agriculture of Clydesdale. London, 8vo, 1810.

8. *Soap waste.*—Page 10, line 22.

The use of soapers' ashes as a manure, was known more than 200 years ago, though it is a commonly received opinion that its application to this purpose is a modern invention. In Platt's *Jewel House of Art and Nature,* 4to, London, 1594, is a wood-print engraving of an ear of corn that was produced from a field which had been enriched with this manure. The writer of the work also states that a good mortar for building may be made by a mixture of two loads of such ashes, one of lime, one of loam, and one of Woolwich sand. He says that just before he wrote, a soap-boiler at Aldgate built a large house for his own family with such mortar, in order to encourage others to buy soap-ashes for the same purpose.—*Ibid.* page 77.

9. *Metallic oxides.*—Page 11, note 14, line 3.

In the beginning of the 17th century, *Jean Rey,* a physician at Perigord, published a work, which is now extremely rare, to prove that the increase which metals acquire in calcination arises from the air. An apothecary at Bergerac having informed him that two pounds of fine tin, during six hours calcination, had increased seven ounces in weight, he answers, "This increase of weight proceeds from the air, which mixes with the calx, and attaches itself to its minutest particles, in the same manner as water adheres, and adds weight, to those of sand."—See Rosier's *Journal,* tom. v. Paris, 1777. This writer surely discovers great sagacity for the time in which he lived; for he must have preceded Mayow nearly half a century, whose celebrated *Tractatus quinque* were not published till the year 1674. A copy of Rey's book was lately discovered in Paris, and an English translation of it has lately been printed in the *Journal of Science, Literature, and the Arts.*

10. *The blood.*—Page 13, note 17, line 2.

The source of the iron in animal blood is very mysterious; for it is well known that the quantity may be increased either by medicine or exercise. "In hard-working people," says Mr. Johnson, "the red particles abound; and by the exercise of

particular parts, the same takes place, as in the wings of those birds accustomed to fly, and in the legs of those accustomed to walk a great deal."—Johnson's *Animal Chemistry*, vol. i. p. 42.

11. *Smelting of ores.*—Page 17, line 2.

The many thousand tons of iron scoria which are here spoken of, lie at Flaxley Abbey in the forest of Dean, seven miles from the town of Ross. It is not only rich in metal, but the proprietors are enabled to obtain better iron from it than can be procured from the original ore.

12. *Sulphate of soda.*—Page 22, note 29.

See the Essay on Glass Making, in the second volume, where the subject is further elucidated, and this salt, under certain circumstances, recommended for the fabrication of glass.

13. *Morocco leather.*—Page 26, line 4.

The manufacture of Russia leather is not thoroughly understood in England. The best account of the process hitherto published, is in Tooke's *View of the Russian Empire*, 8vo, London, 1799, vol. iii. page 514. A respectable tanner in the North of England informed me that there is more of the tanning principle in the root of the common plant called *Burnet*, the *Sanguisorba* of Linnæus, than in oak bark. It is a plant that bears a red flower, and was, a century ago, the clover of the day. He thinks it might be cultivated for cattle, as they are all fond of it; and that it might be plowed up every three years in order to collect together the roots for the purpose of tanning.

14. *Carburetted hydrogen-gas.*—Page 30, line 22.

The house of Mr. Lee of Manchester has for several years past been heated by steam and lighted in a very elegant manner by the gas procured from coal. The works of Messrs. Philips and Lee are also lighted in the same way; and so safe is this mode of lighting apartments considered, that since then the London Insurance Company have offered to insure their works at one-half of the former premium.—Buchanan *On the Economy of Fuel*, 8vo, page 251. More than seventy years ago Colonel Cooke suggested the idea of warming rooms by steam. See the *Philosophical Transactions for* 1745.

15. *Intense light.*—Page 30, line 25.

It is so important to obtain an intense light at the public light-houses, that great expense has been incurred in the construction of reflectors of silver. It has occurred to me, that *strontites* and some other substances might be employed to make coloured lights for greater distinction in hazy nights or foggy

weather. If moisture be present in the mixture of strontites with inflammable bodies, the flame will be of the colour of carmine. Thus, if any of the salts of this earth be dissolved in alcohol, the spirit will burn with a flame of this colour. In like manner the flame of any of the salts of barytes, under similar treatment, will produce a brilliant yellow flame, and boracic acid a flame of a beautiful green colour. It has long been known that strontites, barytes, and boracic acid, will produce these colours, but I have not heard of their being used for this purpose.

16. *The distiller.*—Page 33, line 6.

Distillation is a process which is capable of very great improvement. Many important hints on the subject have been published occasionally both in Dr. Tilloch's *Philosophical Magazine*, and in Nicholson's *Journal*; but the latest and best treatise that I have seen is in an octavo volume of three hundred and sixty pages, containing many copper-plate engravings, entitled '*Essai sur l'Art de la Distillation*, par L. S. Lenormand, à Paris, 1811.'

17. *Vinegar stoves.*—Page 34, line 6.

I have been informed that some manufacturers have adopted the expedient of favouring the absorption of oxygen by submitting the vinegar in a continued stream to the action of the atmosphere. This is effected by allowing the acid to flow from a vat into a receiver in which a pump is fixed, and which returns the liquor into the vat as fast as it runs off. The pump is worked by a steam engine.

18. *Sugar.*—Page 34, line 15.

Sugar is said to contain more nutriment in a given bulk than any other known substance. For this and other reasons it would be a proper article when corn is scarce for feeding cattle, if Government would remit the duties. In consequence of such an intention having been entertained (in the summer of the year 1808) I underwent several examinations by a committee of the house of commons, and at their request undertook a series of experiments upon sugar, and also drew up a memoir on the subject, which the committee ordered to be printed, accompanied with their own remarks, for the use of the members of the house. As this memoir contains a variety of new experiments on the nature of sugar, and several curious facts not generally known, I embrace this opportunity of referring to the paper, which will be found in *the fourth Report of the Honourable the West India Committee to the House of Commons*, and also in the *Philoso-*

phical Magazine, where it was reprinted in September of the same year.

19. *Daniel Houghsetter.*—Page 36, note 53.

The patent to work the copper-mines of England was granted to this foreigner in conjunction with one Thos. Thurland, and dated the 10th of October, in the 6th year of the reign of Queen Elizabeth. King James afterwards established by patent, what was called the "London Society of the Mineral and Battery Works," and confirmed the patent granted by the queen to the aforementioned individuals.—Sir John Pettus's *Fodinæ Regales*, folio, London, 1670, page 62—69.

20. *Zinc.*—Page 36, line 6.

I would recommend it to those who have occasion for large quantities of hydrogen-gas to use zinc instead of iron; it not only produces a purer gas, but the sulphate of zinc (white vitriol) that results from the process, would indemnify the operator for his expense in purchasing the materials; whereas, when iron is used, the residuum is of little value.

Hellot speaks of the deleterious powers of zinc, but I do not know that any other writer has considered this metal to be poisonous. A few years ago a mine of zinc-ore was discovered on Lord Ribblesdale's estate at Craven in Yorkshire. This ore is found there in a state of such purity as to have been sold as a substitute for white lead in painting. In the year 1805, Messrs. Hobson and Silvester of Sheffield obtained a patent for a method of manufacturing zinc into wire, also into vessels of capacity, and into rolled plates for a variety of purposes. Zinc is a brittle metal at the temperature of the atmosphere; but these gentlemen discovered that when it is heated to 220°, and from that to 300°, it becomes malleable, and capable of enduring the rolling press or the hammer.

21. *Manufacture of brass.*—Page 36, line 7.

None of the works professedly chemical, that I have seen, have treated of this process. The only account of the manufacture which I can find, is in Doctor Merret's translation of Neri's "*Art of Glass*," page 299, a book of great rarity;—and in Rees's *New Cyclopædia*, vol. v. part 1.

Formerly many of our household articles, such as saucepans, basons, &c. were of polished brass; but now, all such utensils are made of copper. This is certainly an improvident alteration, as the latter metal is not cleaned so easily as brass, and when polished it is much more liable to tarnish.

22. *Black-ash.*—Page 37, line 17.

Black-ash is prepared by the following process. The waste lye which is pumped out of the boiler of the soap manufacturer, is evaporated in large pans of wrought iron, until the salt separates from it, which is removed as it precipitates. These salts, usually consisting of the sulphate, muriate and sebate of soda and potash, are then taken to a reverberatory furnace, where they undergo a heat sufficient to melt and partially decompose them; and when they are in a state of pasty fusion a hole is opened in the side of the furnace, through which the matter flows into an iron pan placed underneath to receive it. This saline mixture, freed from much of its impurity by the process, becomes a ponderous and solid mass as it cools, and in this state it is sold again to the soap-boiler for the manufacture of common yellow soap.

23. *Salt-petre.*—Page 38, line 27.

Salt-petre might probably be made to considerable advantage in certain situations in Great Britain. Wherever stables or cowhouses are so situated that the floors, on one or more of the sides, are considerably above the surface of the ground, an abundant efflorescence of salt-petre will generally be found between the joinings of the bricks, it being formed from the urine of the cattle, assisted by the combined action of the air and the lime of the mortar used in the construction of the buildings. A particular account of the method of collecting and crystallizing salt-petre in the East Indies will be found in the *Philosophical Transactions for* 1665, page 103.

A most interesting detail of the methods by which a very extraordinary collection of salt-petre was formed throughout the several provinces of France, in a case of great emergency, is printed in the *Tradesman,* or *Commercial Magazine,* vol. ii. page 533.

NOTES TO ESSAY II.

24. *Material substance.*—Page 48, line 2.

The question whether caloric be a *material* ponderable substance, or only an effect produced by a particular motion excited among the particles of bodies, has long divided the opinion of many eminent men. Zeno, the founder of the sect of the Stoics, maintained the former position. Lord Bacon and other philosophers of his time were of the contrary opinion. Those who are desirous of investigating this curious subject may read

Cicero *De Natura Deorum*, on the one side, and Bacon *De Forma Calidi* on the other. Count Rumford has likewise endeavoured to prove by many experiments, that caloric is not a material substance.—See *An Inquiry concerning the Nature of Heat*, by Benjamin Count of Rumford, in the *Philosophical Transactions for* 1804.

25. *Enlarging its bulk.*—Page 60, line 11.

The expansive force of water when in the act of freezing is a curious subject. Many interesting particulars will be found in Mr. Boyle's work already quoted, in pages 86, 90, 204, &c. A modern traveller has also noted the following circumstances which occurred in Canada in the winter of 1806 or 1807. "Experiments," says he, "have been made on iron shells, by military men, to ascertain the expansion of freezing water. After having nearly filled the shells with water, iron plugs were strongly driven in at the fuse-hole by means of sledge hammers; but they could never be so firmly fixed as to resist the expanding ice, which some time afterwards pushed out the plugs with great force and velocity; a bolt or cylinder of ice immediately shooting up from the hole. When a plug was used with springs to lay hold of the inside of the shell, so that it could not possibly be pushed out, the force of the expansion split the shell. The great distance to which these iron plugs were thrown shows the amazing power of the expansion of frost; a plug of $2\frac{1}{2}$lb weight being thrown 415 feet from the shell.—*Letters from Canada*, by Hugh Gray, 8vo, London 1809.

26. *Change of temperature.*—Page 62, line 1.

Not only animals and vegetables, but mineral bodies also, are affected by the changes of atmospheric temperature. Metals are well known to expand or contract by such alteration; and in the 75th volume of the *Philosophical Transactions*, General Roy has shown that the expansion of the steel pendulum of a clock is such, that every four degrees of the thermometer will cause a variation of a second per day in the going of the clock. See an Essay on this subject in Nicholson's *Journal*, 4to, vol. i. page 56. Brass wire will be absolutely altered in its nature, merely by being suspended in a *damp* atmosphere. Madame Roland describes a very singular kind of harp which she says she saw in the garden of Mr. Haz, type-founder at Basle in Switzerland, which must have been made on this principle of expansion. "It is composed," she says, "of fourteen wires, closely disposed, fastened at one end to a pavilion, and at the other to a wall at the extremity of the garden, and at the distance of about 500 feet. The variations of the temperature of the atmosphere excite the vibrations of these wires, and make

them sound in a singular manner. In settled weather, constantly fair, or constantly rainy, the instrument is silent. If any change is to happen, if any distant storm is rising, of which no appearance is yet perceived,—if contrary winds are ready to contend for empire, the aërial music begins, and thus announces the revolutions of its element sometimes twenty-four hours beforehand."—Madame Roland's *Tour through Switzerland.*

27. *Capacity for caloric.*—Page 66, line 11.

Boerhaave taught that heat was distributed among bodies according to their respective quantities of matter; but nothing can be more erroneous. Leslie has shown that mercury contains not the thirtieth part of the quantity of caloric which is lodged in an equal weight of water at the same temperature.—Leslie *On Heat*, 8vo, London 1804, page 529. An extended table of the capacities of bodies for caloric will be found in Dr. Henry's *Elements of Experimental Chemistry*, vol. ii. page 528.

28. *Preservation of animal heat.*—Page 67, line 13.

Nature has not only provided for the preservation of animal heat in cold countries, but has enabled us, by certain contrivances in the animal economy, to resist the injury to which it is natural to suppose we should be liable in very *hot* climates, as may be seen at page 155 of this Essay. It is probable, as Count Rumford has shown, that the black colour which nature has given to the skin of the Negro, was designed with the same beneficent intention. "It is well known," says he, "that Negroes support the heats of tropical climates much better than white people. Is it not probable," he continues, "that their *colour* may enable them to throw off caloric rays with great facility and in great abundance? and that it is to this circumstance they owe the advantage they possess over white people in supporting heat?"—*Philosophical Transactions for* 1804.

29. *Production of animal heat.*—Page 69, line 1.

We have seen how animal heat is obtained and preserved; but the methods which nature employs for the production of that portion of caloric which is necessary for the preservation of *vegetable* life are not so apparent. Sir James Edward Smith, though he does not explain this matter, has, however, published a very remarkable fact. He states, on the testimony of Lamarck and Sennebier, that the flower of the Cuckoo-pint, the *Arum maculatum* of Linnæus, contains a greater degree of sensible heat than any of the plants or flowers that grow around it.—Dr. Smith's *Introduction to Botany*, 8vo, London 1809.

30. *Lamps for coal-mines.*—Page 131, line 25.

The Chamber of Commerce and Manufactures at Mons has directed the publication of an interesting pamphlet on the use of Sir Humphry Davy's safety-lamps. The report states that there are no less than 100,000 persons employed in working the coal-mines in the province of Hainault, and that they conceive it is "an inappreciable benefit which they confer," by making known the lamps above mentioned. From this account, it appears that the lamp has been as useful in the mines of Flanders, as in those of England, no accident having occurred in those mines since it was adopted.—See Dr. Thomson's *Annals of Philosophy*, vol. ii. page 394.

31. *Warmth of apartments.*—Page 143, line 24.

"The Chinese, in order to defend them from the piercing cold which they experience in the northern parts of the empire, have devised subterraneous furnaces placed outside the houses in excavations made on purpose. Tubes go branching off from these furnaces in all directions, under the bricks of the floors, and under a kind of platforms or *estrades* on which the Chinese sleep. They even pass through the walls which divide the different rooms, so that the heat diffused by these tubes produces in the apartments the temperature desired. The fire is kept up night and day in the outer stove or furnace, without the smallest danger to the buildings, because a coat of bricks closely confines the flame, and opposes its disastrous effects. If the apartments be spacious and numerous, an increased number of stoves and tubes always ensure the desired result."—Van Braam's *Embassy to China*, vol. ii. pages 65, 66.

32. *A succedaneum.*—Page 160, line 5.

Since this account was written I have been informed that some other manufacturers have been in the habit of using the small of pit-coal as a succedaneum for iron stoppers to their furnaces; and on inquiry I find that glass-makers stop up the mouths of their ovens with small coal, on the principle of its being a non-conductor of heat, and that this contrivance answers their purpose completely. It appears also, that iron-founders stop up their air-furnaces in the same manner.

33. *Materials of the best kind.*—Page 164, line 19.

When treating on the construction of chemical furnaces, I inadvertently omitted the directions which I had intended to give for the preparation of the MORTAR. The following observations may however be useful if inserted here. In erecting furnaces which are intended to sustain a great heat, the compo-

sition of the mortar is of the utmost importance. When I was in the habit of using stone-lime, such as is produced in several of the midland counties of England, I found the following proportions made the hardest and the best mortar.

Lime fresh burnt, and measured while in lumps, one bushel; sharp river sand, well washed, four bushels. The whole to be intimately mixed and thoroughly tempered.

For the internal parts, which are not exposed to the air, a still larger proportion of sand might, I found, be used with advantage.

The best proportions for common chalk-lime are, lime one bushel, and sharp sand two bushels; though that which is thoroughly and uniformly burnt will take three bushels of sand to one of lime.

It has long been a general complaint that the common chalk-lime contains a considerable proportion of unburnt stone, or carbonate of lime, which is a great loss, and renders it difficult to ascertain the exact measure of sand that ought to be used with it.

In consequence of this, some lime-kilns have been erected at Bow and elsewhere in the neighbourhood of London, with chimneys which rise thirty feet above the body of the kiln; and these occasion so powerful a draught that the complaint just mentioned is entirely obviated.

The Earl of Stanhope has also erected lime-kilns on a new principle for burning lime in such a manner that it may be delivered to the consumer in a perfect state.

In the *Journal de Physique* for the year 1775, page 311, are a plan and a description of a kiln for burning lime *after* it has been once slacked and reduced to powder. The design of this is, that it may be used in mortar quite hot. It is recommended to be employed in the following proportions, and it is said that such mortar will become extremely hard and durable.

	Parts.
Fine sand	3
Well burnt brick, ground	3
Slacked lime	2
Lime slacked in the air, and afterwards recalcined	2
	10

The stone consistence which mortar acquires is owing partly to the gradual absorption of carbonic acid, and partly to the chemical combination of a portion of the water which is employed in making it. Hence, if lime reduced to powder and then recalcined, or burnt lime reduced to powder without being

slacked, be added to mortar, the mortar when dry will acquire much greater hardness than it otherwise would.

For the different works at Woolwich and elsewhere, belonging to Government, all the lime which is consumed in making mortar is ground while dry to a very fine powder, and used in that state without being previously slacked. It is taken from the kiln quite hot, and ground in that state. This prevents that absorption of carbonic acid gas which would otherwise take place; and in making mortar with such lime, as much water is required as would be combined with the lime if treated in the common way, and a much larger proportion of sand may be employed than can possibly be used even with the best lime if prepared after the old manner; and it has often been demonstrated that, provided the mortar have sufficient tenacity, it will form a harder cement in proportion to the quantity of sand employed.

The mortar of the ancients contained more sand than is generally used at present, and the extreme solidity of all the ancient buildings has often been noticed. Pliny* and Vitruvius† have informed us what were the proportions of lime and sand used in their time, and that it was customary to burn the lime close to the spot where the buildings were erected, that the workmen might have it immediately from the kiln.

"The greatest part of the wall built by King Athelstan in the neighbourhood of Exeter is still remaining. It consists of small unhewn stones as they were dug from the quarry, the interstices filled up with hot lime and rough sand, and faced with ashler work of hewn stone, and the whole strengthened by strong buttresses. The mortar used in this work is from length of time become so hard and durable, that, on attempting to pull down any part of it, the stones are sooner broken than separated one from the other."—Jenkins's *History of the City of Exeter*, 8vo, 1806, page 17.

34. *Lime-mortar.*—Page 165, line 16.

I am inclined to think that the lime made from *chalk* is always the strongest in proportion to the quantity of iron contained in it. I have found that the whiter the chalk the weaker will be the lime that is made from it; whereas that which is made from the dark gray chalk approaches most to the nature of stone lime, and is less perishable by water. The lime made at Dorking in Surry is of this latter kind, and is in great demand for various purposes of building under water. Other in-

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* Lib. xxxvi. c. 23. † *Architectura*, lib. ii. c. 5.

stances in corroboration of the idea now suggested might be easily adduced: thus the chalk of Portsdown-hill in the county of Hants is soft and white, and the lime made from it is used only for common building purposes; whilst the chalk of Butsa-hill, fifty-eight miles from London, and likewise in Hampshire, is a hard gray chalk, making a description of lime which is employed for the foundation works under water of the dock-yard and fortifications at Portsmouth, it being equal or superior to the Dorking lime.

The chalk in the neighbourhood of Ware and Hertford is of the former description, and the lime produced from it is fit only for the commonest building purposes. I have been told that the people who deal in lime on the Croydon iron rail-way, are aware of the value which a mixture of iron gives to the chalk for the purpose of making lime, and that they know how to distinguish the difference there is in this respect in the chalk which is found in the range of hills that runs from Farnham by Guildford and Dorking through the county of Surrey, entirely up to the town of Croydon. When lime is required for *chemical* purposes, that only ought to be taken which is quite soft and white, such as is found within the park at Ware in Hertfordshire.

35. *Steam-engine boilers.*—Page 173, line 26.

As cast iron is so liable to break, from its unequal expansion when submitted to heat, engine boilers and other very large vessels of capacity are now usually made with plates of wrought iron riveted together, at a very great expense. Although these are more costly in the first instance, they are more to be depended upon, and in the end are absolutely cheaper. But it has occurred to me that a very great saving might be made in the construction of engine boilers, if the upper part, which does not at all suffer from the action of the fire, were to be made of cast-iron. This I am sure might be done; and if the two parts were properly united by screws, then, when the bottom is become useless, a new one might be supplied at a comparatively small expense, and the vessel would really be as good as at the first.

36. *Heat of his walls.*—Page 176, line 23.

Garden-walls, hot-houses, and green-houses, if fitted up with steam pipes, might be heated much better than they are at present. Pineries have often been destroyed by overheating the flues; but this would not be so likely to happen if the present mode of heating them by naked fires were abandoned. The great advantage of steam pipes would be, that by means of stop-cocks the temperature might be raised or lowered at plea-

sure, and all gardeners know that different fruits require different temperatures. Lord Valentia, in the account of his travels, says that " at a breakfast which was given him by the Rajah of Seringapatam, besides a profusion of pastry, made dishes, and fruits, several species of the *Solanum* were brought in pots, with the fruit *dressed* and hanging on the plants, which appeared in perfect health. The roots of other plants were also boiled whilst the stems and leaves were never touched." It must surely have required great ingenuity thus to dress a part of a plant without destroying the vegetation of the other.—*Voyages and Travels to India, Ceylon, the Red Sea, Abyssinia, and Egypt, by* George Viscount Valentia, in 3 vols. 4to, London 1809.

37. *Impaired by boiling.*—Page 186, note 124, line 4.

In making decoctions of dye-woods, it is often important not to exceed a certain temperature; but this is very difficult to be attained by boiling them over a naked fire. Recourse has therefore been had to the expedient of conducting these processes by the agency of steam. It has however been found, that where vessels are heated by the steam being thrown *within-side* them, the contents cannot be made hotter than within one or two degrees of the boiling temperature; whereas if one vessel be fitted within-side another vessel, and the cavity between them be regularly supplied with vapour from a high pressure steam-engine, and accurately closed so as to preserve every portion of the steam from escaping, the water or other liquid in the inner vessel will be readily brought to a full boiling heat, and it will acquire this temperature even much sooner than a similar vessel with its contents would, if placed over an open fire, or fixed in a common furnace of brick-work as boilers usually are.

Being some time ago at a large manufactory in the North of England, where the proprietors are as obliging and communicative as they are scientific and intelligent, I took the opportunity of making some experiments as to the time that vessels of this latter construction require, in order to be fully heated by steam. These gentlemen have a row of five small coppers, purposely for making colours, and they are as completely fitted up as could well be devised. An iron pan that has a broad flange is first set in the brick-work, with a furnace door as usual. Within this iron pan a smaller one of copper is fixed, having a small flange by which it hangs so as to preserve it about an inch from the outer one in every part. A strong hoop of wrought iron is then laid upon the flanges of both, with a layer of cloth between, and riveted on, so as to make the whole air-tight. A steam-pipe communicates with the outside of each of these copper boilers; therefore, by merely turning a small cock, the steam rushes into the space between the two vessels,

and heats in a few minutes the copper pan with its contents.

The vessel I made choice of for my experiments measures 18 inches deep, 20 inches in diameter at the top, and is of a capacity to hold 20 gallons. This was filled with cold water taken immediately from the river, the temperature of which was at 52° of Fahrenheit. When the steam had been turned on six minutes, the 20 gallons of water were raised from 52° to 190°, in two minutes more to 200°, in other two minutes to 208°, and in one minute more, making in the whole eleven minutes, to 212°.

Being desirous however of taking the temperature at shorter intervals, I fixed upon another copper of the same dimensions that was fitted up in the same way; and as this, like the former, was quite cold, not having been used for some time, it was very proper for my purpose.

When 20 gallons of water at 52° were measured into it, the steam was turned on, and the time accurately noted by a stop-watch.

In 1 minute the water rose to ..	82°	7½	193°
2	108	8	198
3	128	8½	201
3½	137	9	203
4	146	9½	205
4½	154	10	206½
5	162	10½	208
5½	169	11	209
6	176	11½	210
6½	182	12	210½
7	188	12½	211
		13	212

This vessel was in the form of an inverted bee-hive, with the bottom brought to a small point; that in preparing colours any sediment might be the more readily collected together and removed. The outer vessel is of cast iron, the inner as before said of copper, with a space of about an inch between them. A pipe is adapted to the bottom of the outer vessel, with a stop-cock for occasionally drawing off the water that proceeds from the condensed steam; for, if this be not done frequently, it retards the heating of the inner vessel. To the want of proper attention to this I attribute the difference in the time which was required in these experiments to bring the water to a boiling heat; for, though both vessels were of the same capacity, the one boiled in eleven, whilst the other required thirteen minutes; though the treatment in every other respect was the

same. The outer vessels are lapped over with straw, and so are the conducting pipes; and both are then neatly plastered with mortar, to prevent any unnecessary escape of caloric. The main pipes are of cast iron, screwed together by double flanges; the smaller pipes are of lead—although copper is better for these, lead being very liable to bend and become out of order.

It may be remarked, that where boilers are heated in this way, the water shows no appearance of ebullition till it actually boils; whereas, when the steam pipes are in connexion with the liquor intended to be heated, the water appears to boil long before it acquires a boiling heat, and the fact can only be ascertained by the use of a thermometer. This circumstance, which is often very inconvenient, gives the application of heat on the *outside* of the vessel, a decided preference.

This last method of applying the heat has also other considerable advantages, which I will endeavour to enumerate. In extracting the colouring matter from some woods and other dyeing materials, it is of consequence not to exceed one particular temperature, which varies according to the purpose intended, and also according to the nature of the articles employed: now, in this mode of heating the vessels, the temperature can be varied in any way that may be desired, and any process may be so conducted, that the materials may be preserved for any specified time, or even throughout the whole day, at any given heat between that of the atmosphere and boiling water. This is effected by turning the stop-cock so as to let in no more steam from the steam boiler than experience has shown will be sufficient for the desired purpose. But it occurs to me that it would be an improvement in the apparatus if the stop-cocks were to be graduated in accurate divisions: a few experiments would then ascertain that scale of temperature which would always be produced by the respective numbers, and these in all cases should be marked sufficiently plain to prevent the possibility of mistake.

In preparing some of the colours for calico-printing, the decoctions are boiled with flour-paste for a very considerable time, until the whole becomes a thick mass. In this process, if the heat be given as usual by a coal fire underneath the vessel, it is extremely difficult, if not impossible, to prevent the matter from burning in some measure by its adhesion to the sides or the bottom of the pan, and this never fails to affect the beauty of the colour, independently of the loss that is sustained by that portion which actually becomes carbonized by the accident. Now, wherever steam is employed in preparing colours, this effect cannot happen; and though the colour may perhaps be injured by its being treated at too high a temperature, it can never suffer by burning to the bottom of the vessel; for the heat is

equal in every part, and can never be so great as to produce this effect.

In those manufactories where a steam-engine is employed, it would be an easy matter to convey a pipe from the boiler, that shall not only effect all these purposes, but also warm all the rooms of the buildings contiguous to it. In this case, a small additional pipe with a stop-cock might be fixed to one of the main pipes, which would also furnish the manufactory with distilled water, and this at no additional expense of attendance or fuel. Moreover, by fixing a small pipe in a vertical direction to the main pipe that passes through the colour-house, and securing this additional pipe with a stop-cock, any small quantity of colour might be quickly prepared in an extemporaneous way, or any loose detached vessel might be heated to a given temperature in a few minutes with the greatest convenience. To effect this, all that is necessary is to bring the vessel containing the materials to be heated, to this vertical steam-pipe, and fix it so that the pipe shall dip into the fluid, and go within-side down to the bottom of the vessel. If the cock be now turned so as to let in the steam, any degree of heat may be given to it, between that of the temperature of the air and actual ebullition. This will be convenient, not only for making colours, but for medical decoctions, pharmaceutical operations, and various other processes that will suggest themselves to the mind of an intelligent reader. Even boiling water itself is a very desirable thing to have always at hand in large manufactories: this, where there is plenty of steam and an apparatus of this kind, may at all times be procured with the greatest facility. A gallon of cold water, brought immediately from the spring, may be made to boil in two minutes by turning the steam from one of these pipes into it.

For the preparation of pharmaceutical articles, by means of steam, it would be advantageous to have two small copper vessels, one to receive the steam within, and the other on its outside, and so contrived that they might at any time be adapted to the steam-pipe of a common cooking apparatus, such as is now to be found in many of the best kitchens in this country. These additions to the common apparatus can be made at a small expense, and they would render the whole so complete that every pharmaceutical process of digestion, decoction, distillation, or boiling, might be performed by it with profit and advantage. A very complete apparatus for the preparation of pharmaceutical articles by means of steam, has been erected by the Company of Apothecaries, at Apothecaries'-hall London, and found very useful and highly economical.

Indeed, for most of those processes that would require no higher temperature than that of about 208° any common culi-

nary utensil, either of earthenware or metal, might be employed, and this would fully answer for most purposes.

38. *Hot-pressed.*—Page 187, line 2.

A considerable expense and some uncertainty attend the operation of hot-pressing that species of stuff goods called bombazets, besides a waste of heat that is truly surprising. It has occurred to me that an important improvement might be made in the process, and therefore I think it right to describe the operation as it is now conducted, and then suggest the alteration I would recommend. In the manufactory which I had the opportunity of inspecting, they have six very powerful presses, each of which will contain at least thirty pieces of goods when piled singly one above the other, with a cast-iron plate one inch thick between each piece. As the pressure would not produce the desired effect without heat, they obtain this by heating the iron plates preparatory to the operation. For this purpose they have two very large ovens, each of which has an iron bottom several inches thick; and when these ovens are to be used, fires are lighted underneath them, and kept burning until the bottom becomes of an intense red heat. These ovens are for the express purpose of heating the iron plates; but as the workmen have no means of ascertaining with accuracy when they are of a proper heat, they usually keep them in the oven until they are nearly red-hot; they are then drawn out, and the heat lowered, by placing a cold plate of iron between each of them. In this state they remain for an hour or two, exposed to the cold atmosphere, till the superadded plates become nearly of the same temperature. But notwithstanding this precaution, they are often found too hot to put between the goods at a time when the presses are emptied to receive them; they are therefore sprinkled with water to cool them to that particular point when they may be used with safety. The iron plates which I saw employed, were twenty-one inches long, ten inches wide, and one inch thick. The pieces of bombazets are folded with a sheet of that kind of glazed pasteboard known by the name of press paper, placed between each fold; and when the whole piece is thus folded up, it is of a proper width and length to be exactly covered by three of these hot iron plates laid side by side of each other. When a piece thus folded is placed in the press, and covered with three of the iron plates, another piece is laid upon it, which is covered with plates in like manner; and this alternate arrangement of the manufactured goods and the iron plates is continued until the press becomes full.

It appears to me that it would be easier and cheaper to have steam chests adapted to each of the four sides of these presses,

and also between the goods occasionally, if the steam at the sides only should be found to be insufficient!

NOTES TO ESSAY III.

ON SPECIFIC GRAVITY.

39. *Purity of the metals.*—Page 205, line 9.

In the year 1670, Mr. Smethwick, a Fellow of the Royal Society, published a table of the weights of a cubic inch of several of the metals, which was printed in one of the early volumes of the *Transactions of the Royal Society*. It was afterwards published in a small octavo volume, entitled "*The Secrets of the Goldsmith's Art*," London, 1676. Dr. Musgrave also published a table of the specific gravity of various bodies, from experiments made hydrostatically. See *Philosophical Transactions*, No. 169. Mr. John Caswall, in the year 1693, likewise published a table of specific gravities, under the signature of J. C. This was printed in the *Philos. Trans.* No. 199.

40. *Accurate weights.*—Page 207, line 23.

The weights which Dr. Davies employed in taking specific gravities appear to have been very suitable and convenient. "Those I have provided for myself," says he, "have a troy ounce for their integer, and my least weight is the thousandth part of that quantity, differing from the half of a troy grain only as 24 does from 25, which is inconsiderable so far as those small weights are concerned. My four smallest are respectively of 1, 2, 3, and 4, of those thousandth parts, and together make ten, or an unit of the next denomination, that of the 100th part of an ounce. I then have four others, making 1, 2, 3, and 4, 100ths, and *together* the unit of the next denomination, or one-tenth of an ounce, and so on. By these I save the trouble of reducing the common weights to their lowest denomination in every experiment, and sometimes perhaps avoid making mistakes."—Dr. Davies's *Tables of Specific Gravities*, page 27.

41. *Specific gravity of gases.*—Page 216, line 27.

Mr. Leslie has devised a new method of ascertaining the specific gravity of gases; which consists in observing the time that is required for emptying a vessel through a very small orifice, by means of the pressure of an equal column of water. I have not had an opportunity of witnessing the experiment, and therefore can give no opinion as to its accuracy; but I thought it worth while to advert to it.

NOTES TO ESSAY IV.

ON CALICO-PRINTING.

42. *Alum.*—Page 251, line 3.

Professor Beckmann, in a memoir published in the *Gottingen Philosophical Transactions for the year* 1778, and also in his *History of Inventions and Discoveries*, has asserted that alum was entirely unknown to the Greeks and Romans; and that the triple salt, the true sulphate of alumina and potash, was first discovered in the East so late as the 12th century.

Herodotus mentions Egyptian alum, and says when the people of Delphos were collecting a contribution to rebuild their temple, the King of Egypt sent them a thousand talents of alum.—Herodotus, lib. ii. cap. 180. Diodorus Siculus and Pliny say that the island of Melos was celebrated in their time on account of its alum. But Mr. Beckmann asserts that the article which these writers refer to was *martial vitriol*, and not alum, and that it was celebrated in medicine, and used for dyeing black. He proceeds to remark, that the invention of the true alum must have been later than the 12th century; that in the 15th century there were alum-works in the neighbourhood of Constantinople, and that in the middle of that century the discovery was brought into Europe.

One of the earliest works in Europe for the manufacture of alum was at Tolfa in the Italian States, founded by the son of a celebrated lawyer who traded to Constantinople in Italian cloths, and took that opportunity of making himself acquainted with the method of boiling alum. In England the first alum-work was erected at Gisborough in Yorkshire, in the reign of Queen Elizabeth, by Sir Thomas Chaloner, an ancestor of the present representative in parliament for the city of York, who, notwithstanding the anathemas of the Pope, was warmly patronised in his own county by Lord Sheffield and other neighbouring landholders. King James also undertook to promote this work, taking care to appropriate to himself a monopoly of it, and to forbid the importation of foreign alum.—See Beckmann's *History of Inventions and Discoveries*, vol. i. page 288. Anderson's *History of Commerce*, vol. iv. page 406. Pennant's *Tour in Scotland*, 4to, Warrington 1774, page 23. Campbell's *Political Survey of Great Britain*, 4to, vol. i. page 75, and vol. ii. page 20.

Notwithstanding this positive assertion of Professor Beckmann, I think alum must have been known much earlier, from many considerations, especially from the perfection to which the art of dyeing had attained in several parts of the East, and

in some countries of Europe; and also from some Asiatic proverbs and superstitions which are connected with this salt. It was an opinion of Mr. Harmer, that the practices and customs of the East are the same now as they were several centuries ago; and the superstitions of a people are generally of great antiquity. Dr. Russell gives the following relation: "Of all the species of superstition, that of the Arabian belief of the influence of *evil eyes* is," says he, "the most extraordinary. Children are supposed to be more liable to this malignant fascination than others, and they are provided with various charms for their defence; but the most depended upon is a piece of *alum* fastened upon the head-dress of the child. The alum, as they assert, intercepting the baleful influence of the eye, is split by it into pieces, and the child remains unhurt." Dr. Russell relates, that while he was at Aleppo he heard it asserted, and it was generally believed, that a Kurdeen lately deceased had been known to crack a large crystal vase, by merely looking at it with steadfastness from a distance.—Dr. Russell's *Natural History of Aleppo*, in two volumes, 4to, London 1794.

There is now a large manufactory of alum in the neighbourhood of *Latera*, which is about twenty-five leagues from Rome. The alum is procured from a mine called *del Mulino*; this mine was explored by the Abbé Fortis, who has written an interesting account of it in the *Memoirs of the Royal Academy of Sciences at Paris for the year* 1777. Most of the British alum is prepared in the neighbourhood of Glasgow;—at a work belonging to Lord Dundas, near Gisborough in Yorkshire; and at Whitby in the same county. For further particulars consult *The Chemical Catechism*, 10th edition, pages 100, 130, and 188. A Report made by Berthollet and Dietrich to the Royal Academy of Sciences the 10th June 1789, "on the constituent principles of alum and the manner of its formation," will be found in the *Annales de Chimie*, tome iii. page 46—54.

43. *Ancient purple.*—Page 251, line 13.

Mr. Bruce was of opinion that what has been said by the ancients respecting the purple fish of Tyre, was only designed to cover and conceal their knowledge of *cochineal*. For, says he, "if the whole city of Tyre had applied to nothing else but fishing, they could not have coloured twenty yards of cloth in a year."—Bruce's *Travels to discover the Source of the Nile*. Introduction, vol. i. page 63. There is, however, a shell-fish found in great abundance near Hastings in Sussex, and on other parts of the English coast, which has the property of dyeing a very permanent purple. I have myself given a stain to calico with it, that no washing or exposure to the sun and weather has removed. Those who wish to investigate this subject may con-

sult a Memoir by Mr. Cole in the 15th volume of the *Philosophical Transactions*;—one by Monsieur Reaumur, in the *Mém. de l'Academie Royale des Sciences*, &c. an 1711;—one by Duhamel in the volume for 1736; and a paper by D. Peysonnel, in the *Philosophical Transactions*, vol. 50. There is a lengthened "memoir on the management of the Cochineal insect in the French American colonies," by M. Thiery de Menonville, *Annales de Chimie*, tome v. page 107—137.

44. *Merchandize of tin.*—Page 252, line 1.

The people of Cornwall and of the Scilly Islands understood the arts of refining and working this valuable metal several centuries before the first Roman invasion. Diodorus Siculus says that "those Britons who lived near the promontory Belcrium, (the Land's End) by means of their conversation with merchants which come thither for tin, are more civil than the rest to strangers. They dig their tin out of a stony ground; and when they have dilated it by the fire, they carry it to a certain British island called *Icta*, near which there are places which appear to be islands when it is full sea, but at low water the shore being then dry, they carry over their tin in carts. Out of these islands the merchants transport their tin into Gallia, and from thence they convey it by horses to the head of the river Eridanus."—Cogan's *Diodorus Siculus*, London 1653, page 236. That the Phœnicians made great profit by their trade to Britain for tin, is evident from a story which is told by Strabo, who says that "in the most ancient times the Phœnicians from Cadiz were the only persons who traded to these islands, concealing that navigation from all others." When the Romans once followed a Phœnician ship with a design to discover this market, the master wilfully ran his ship amongst shallows, and the Romans following him were involved in the same danger. The Phœnician, by throwing part of his cargo overboard, made his escape; and his countrymen were so well pleased with his conduct, that they ordered all the loss he had sustained to be paid out of the public treasury."—*Strabo*, lib. iii. By these prudent precautions the Phœnicians enjoyed a profitable and exclusive trade to these islands for about three hundred years. The tin mines of Cornwall have been worked ever since this period. Even so long ago as the year 1198, Henry de Casteilun, chamberlain of London, charges himself with 379*l.* 18*s.* (a large sum in those days) which he had received in fines from the merchants of London for leave to export tin.—Madox's *History and Antiquities of the Exchequer*, folio, London 1711, page 531. Dr. Campbell says that the mines of Cornwall produce annually two hundred thousand pounds worth of tin, which is four times as much as they did in the last century.—Camp-

bell's *Political Survey of Great Britain*, vol. i. page 40. The quantity of tin raised is so much more than the consumption of Europe requires, that the miners of late years have allowed the East India Company to take sometimes one-half and at other times two-thirds of the whole quantity raised, at the low price of 70*s.* per cwt., which is not more than two-thirds of the usual price; a circumstance which very much enhances the price of tin to the British manufacturers. The Prince of Wales receives a royalty of 4*s.* 4*d.* per cwt. from about 3500 to 4000 blocks quarterly, each block weighing on an average three hundred weight and a quarter; besides which, he has the perquisite of a piece cut off the corner of each block when it goes to Truro or Penzance to receive the royal stamp.

45. *Laid on with a brush.*—Page 256, line 9.

As all the colours on Indian calicoes are imparted by the pencil, it appears to me that whenever the trade to the East is completely open, a fine opportunity will be afforded of selling immense quantities of British printed goods; for though this is an article of manufacture which the East India Company has not yet been able to introduce, on account of the attachment of the natives to their own peculiar style of work, yet the case might be otherwise, if the country were regularly supplied with British goods, printed in a style suitable to that market, and in colours equally permanent with those of their own production. The difference there would be in price is almost incalculable; for patterns which would require several weeks to complete in India, might, by means of the copper-plate-press and the cylinder, be done here in a few hours.

46. *Weaving calicoes.*—Page 264, line 11.

The injury which the calico-printer sustains from the improper dressing of the cloth by the weaver, has a better chance of being obviated now than formerly, because the majority of the white calicoes are fabricated in large establishments; whereas in former times most of the goods of this sort were got up by individuals in their own cottages, distributed throughout the counties of Lancaster and York. Some account of the injury which the weaver does to the piece by improper dressing, may be seen in the Essay on Bleaching, in the second volume; and it occurs to me, that where large quantities are woven by steam, an intelligent printer might put the proprietors of these works upon some method of dressing the warp, which would not have an injurious effect in any of the subsequent processes of calico-printing.

Weaving calicoes by steam was adopted nearly twenty years ago by Messrs. Horrocks and Co. of Stockport in Cheshire,

and by other individuals at Glasgow; but since then Messrs. Lightholder and Anderton at Chorley in Lancashire have had a large establishment for weaving calicoes by steam on a new principle. Being desirous of seeing this manufactory, in the year 1813 I obtained permission of one of the proprietors to view it, who attended me himself, and with the utmost politeness explained to me the nature and use of every part of the machinery. The first room I entered was full of machines for dressing the warp. This is done by hard brushes about four feet long, attached at each end to a strap that is carried round a small wheel, so that the brush revolves with it, and at every revolution brushes the warp, which is properly extended, and passes during the operation slowly from one roller, and is wound by the machinery upon another situated at some distance from it. At every revolution of the brush, the warp dips into a long narrow trough of thick flour paste, which is designed to keep the whole moist and make the brushes work well: the whole of these motions are given to the machinery by steam. In the upper rooms there are 60 looms, which are constantly in motion. The shuttles move with great rapidity, and one woman is found to be sufficient to attend three looms. There are two steam engines required to effect the whole of this work; the one is a 17-horse power, the other of the power of 6 horses; and the saving which this apparatus produces amounts to many hundred pounds per annum. Why might not *woollen* cloths be sheared and dressed by machinery?

47. *British gum.*—Page 269, line 7.

Having only slightly adverted to this substance in the Essay on Calico-printing, it may be expected that its manufacture should in some measure be explained:—For producing the article, all that is necessary is, to expose dry starch in shallow iron pans to the heat of an oven for an hour or more, until it assumes a peculiar colour well known to those who are in the habit of conducting the process. It is then removed from the furnace, and ground to a very fine powder, for sale.

When the starch has acquired the heat of about 600°, it swells considerably, becomes soft, and exhales a very powerful smell. At this time it becomes yellow, and afterwards of a cinnamon brown; when it is drawn from the oven, and allowed to cool.

It is observable that starch by this treatment loses all its amylaceous properties, and acquires the properties of gum. It is soluble in cold water, which is not the case with starch; and, unlike starch, it will not produce a blue compound when its solution is mixed with a dilute solution of iodine. For the other properties of this substance see a memoir by Mons. Doebereiner,

Professor of Chemistry at Jena, in the *Annales de Chimie*, tome xc. page 29—42.

In the years 1817 and 1818, Messrs. Turner, Woodheads & Co. of Rotheram had a tedious dispute with the Board of Excise, in consequence of some officers from that Board having made several seizures of large quantities of British gum which had been prepared in their starch-manufactory, and were seized under the pretence of its being *brown* starch that had not paid duty. There being an act of parliament to restrain the makers of starch from having at one time more than 28lbs of *loose* starch in their possession, under the penalty of 100*l.* on each seizure, and 10*s.* for every pound of starch so found, three distinct seizures of British gum belonging to Messrs. Turner & Co. were made, with a view to the recovery of these penalties, which amounted to more than 3000*l.*

In this exigency I was applied to, and samples of the article seized were sent to me for analysis. These were examined with great care; and when I found that they did not possess the properties of starch, and was assured that it could be proved on oath that the starch from which the British gum had been made had paid the usual duty, I advised the manufacturers to resist the payment of the penalties. Accordingly in the month of February 1818 the cause came on to be tried in the Court of Exchequer, in which I was subpœnaed as an evidence for the defendants; and having obtained permission to repeat the experiments in Court by which I had ascertained the points in which British gum differs from starch, the proofs were considered to be so decisive, especially the one by the solution of iodine, that a verdict was immediately pronounced for the defendants.

48. *Messrs. Grants' machines.*—Page 273, line 25.

Since the Essay on Calico-printing was written, Messrs. William Grant and Brothers of Ramsbottom have removed the cleansing-machines which were there spoken of, in consequence of their having had occasion to take down most of the buildings in which their manufactory was carried on, for the sake of erecting some new works on a larger scale. This establishment I have lately seen; and having been surprised, not only at the greatness of the concern, but also at the judgement which has been displayed in the arrangement of the buildings, and in the adaptation of one part to the other throughout the whole of this extensive manufactory, I obtained leave to make drawings and take measures of the machinery, for the purpose, not only of correcting what was said of the Ramsbottom print-works in the former edition of these Essays, but also to direct the attention of the public to an establishment which does honour to the

country, and reflects the utmost credit on the talents and enterprise of the proprietors.

The new works consist of four large edifices, each of which measures eighty-two yards in length, and is of a proportionate breadth; and as these are placed at right angles to each other, they form a perfect square, and inclose an area of more than an acre and a quarter of land. These buildings are all three stories high, and they are lighted by nearly five hundred windows. Several parts of the erections are fire proof; and the walls, the foundations of which are of stone and of a great thickness, are built with a cement that will not admit the entrance of water. An ornamental building, thirty-six feet square and four stories high, will be erected in the centre of the yard, the upper room of which will be so constructed that the proprietors or overseers may, by means of glasses, obtain from thence a view of the interior of each of the buildings that surround it, so as at all times to be able to see how the work-people are employed throughout the whole of this extensive establishment. The counting-house will occupy some part of this building, and the clock within it will be so constructed, that every workman in each of the long ranges of building will be able to observe the time of the day without leaving his post. An abundant supply of spring water has been brought into every part of the works; and the superabundance of this, together with the supply of river-water, is more than sufficient from one fall to turn twenty dash-wheels and two large wheels for the machinery. There are three steam-boilers, which are employed entirely for heating the dunging and dyeing vessels; of which there are two of the former and fourteen of the latter, all made with wood. The fourteen vessels employed in dyeing are in a square form, each of which measures three feet six inches by five feet nine inches; and three feet three inches in depth. The cleansing vessels are each twelve feet long by four feet wide, and about four feet deep. These are all boiled by means of steam.

In erecting this establishment, the proprietors have evidently studied neatness and elegance as well as usefulness; and in the whole of their machinery they seem to have availed themselves of every new invention that can be considered an improvement in calico-printing.

As these works are situated upon the river Irwell, the proprietors have contrived to sink the foundations of their buildings lower than the bed of the river, so as to occasion the water to flow round the outside of the walls, and entirely encircle the whole of the manufactory. This artificial stream is eight feet deep, and of a breadth so considerable, that while it furnishes every part of the establishment with an abundance of water, it effectually preserves it from nightly depredators, and from the

secret approach of those who might otherwise attempt to visit it for the sake of carrying off the peculiar and improved processes of the manufactory. It is the opinion of good judges, that these print-works will be capable of beginning and finishing one thousand pieces per day throughout the year; and that, when completed, they will be the largest and most convenient works of any in Europe.

49. *Varieties of shades.*—Page 303, line 10.

It may add to the resources of some calico-printers and dyers to inform them that "A Letter from M. Jean Michel Haaffmann to M. Berthollet on the Theory of Dyeing," may be seen in the *Annales de Chimie*, tom. vii. page 237; and also an Account of some Attempts to dye Worsted, Silk, Cotton, and Linen Cloth, with the Wood of the Damascus Plum-tree," in *Annales de Chimie*, tom. xix. page 371. Some valuable papers on dyeing will also be found in the several volumes of Nicholson's 4to and 8vo *Journals*.

50. *Logwood.*—Page 310, line 4.

The art of dyeing must surely have been ill understood in the 16th century, for the Government of Queen Elizabeth to have procured a statute to be enacted entirely forbidding the use of logwood. It is entitled "An Act for the abolishing of certeine deceitful Stuffe used in dyeing of Clothes, &c." The preamble states, that "whereas there hath been brought from beyond the seas a certaine kinde of stuffe called logwood, alias blockwood, wherewith divers dyers, &c." and "whereas the clothes therewith dyed, are not only solde and uttered to the great deceyte of the Queenes loving subjects, but beyond the seas to the great discredit and sclaunder of the dyers of this realme, &c.;" for reformation whereof, be it enacted by the Queene our Soveraygne Ladie, that all such logwood, in whose handes soever founde, shall be openly burned by authoritie of the Maior, &c." This prohibition was renewed in the 39th year of the same reign, subjecting the person so offending to imprisonment, and on conviction thereof to stand on the pillory in the market town where the offence was committed.—See 23*d of Elizabeth*, cap. ix., also 39*th of the Queen*, cap. xi. Eighty years elapsed before the real virtues of this useful substance were acknowledged. It has, however, been discovered that this wood is one of the wost valuable articles the dyer possesses, especially for dyeing blacks. A black may be procured by the combination of several vegetable substances with the peroxide of iron: but I have reason to believe that neither galls, madder, nor any other vegetable, will produce a fine black on cotton if logwood be entirely omitted. Hence, all the most approved receipts for writing ink, include logwood as a principal ingredient.

NOTES TO ESSAY V.

ON BARYTES.

51. *Sulphate of barytes.*—Page 317, line 15.

In addition to the various kinds of native sulphate of barytes already mentioned, it may be proper to notice the foliated baroselenite of Kirwan, or what Jameson calls the straight lamellar heavy spar, because it has been applied to some peculiar uses to which the other species are not applicable. It occurs massive as well as crystallized in different forms, and of a great variety of colours. It is found in veins in the different primitive rocks; and beautiful crystallized varieties are brought from the lead mines of Cumberland, Durham, and Westmoreland; it is known also on the continent of Europe and in America. It is sometimes used as a dressing for land; and when burnt and finely ground, it has been used instead of bone-ash for making cupels. The white varieties of the foliated baroselenite have been employed as white colours in painting, and for pastil-pencils; and it has sometimes been used as a flux for ores of particular kinds *.

"The granular baroselenite is one of the rarer species of this genus of ponderous earth. That of *Peggau* in the duchy of Stiria occurs of a beautiful milk white colour, is massive, resplendent, finely grained, semi-indurated, and brittle. It bears a very strong resemblance to the white fine-grained Carara marble, to such a degree, that, by its mere appearance, it might easily be mistaken for it, were it not for its greater specific gravity, which is 4.380, and by which it is readily distinguished."—On analysis it is found to consist of

Barytes	60
Sulphuric acid free from water	30
Silex	10
	100

For an account of several experiments on this mineral, see Klaproth's *Analytical Essays*, vol. i. page 375.

52. *Barytes and strontites.*—Page 343, line 9.

Having in the Essay on Barytes adverted only to the most striking marks of difference between that earth and strontites, I

* Jameson's *Mineralogy*, vol. ii page 275.

am desirous in this place of noticing the other differences which have been observed respecting them.

Muriate of strontites is much more soluble in hot water than in cold; muriate of barytes on the contrary is nearly as soluble in cold water as in hot, and crystallizes by evaporation. An ounce of pure water at 70° dissolves 9 drachms and 50 grains of the former salt; whereas the same quantity of water at the same temperature, only dissolves 3 drachms and 35 grains of the latter. The former produces 25° of cold by its solution; the latter not more than 5°. Carbonate of barytes is highly poisonous; carbonate of strontites may be taken internally without danger. The usual colour of carbonate of barytes is a yellowish or grayish white; the colour of carbonate of strontites is usually light green, though it is sometimes found colourless and transparent. When both these native salts are submitted to heat, it is found that the carbonic acid is less strongly retained in the carbonate of strontites than in that of barytes.—See Pelletier's *Observations on Strontites, Annales de Chimie*, vol. xxi. p. 113; or Nicholson's 4to *Journal*, vol. i. p. 518 &c..

53. *Dr. Crawford.*—Page 360, line 15.

This eminent physician, who made more experiments on the effect of barytic salts on the animal economy than any other individual, has remarked that "it is of great importance that a saturated solution should be used, in order that the dose may at all times be adjusted with sufficient accuracy." This accuracy seems, however, to have been fully accomplished by the Edinburgh College in their Pharmacopœia, in which they prescribe one part of dry crystals of muriate of barytes to be dissolved in three parts of distilled water.—See *The Edinburgh New Dispensatory*, by Dr. Duncan jun., 4th edition, Edin. 1808, page 480.

Dr. Crawford's memoir is, however, well deserving of the perusal of all those who are likely to be engaged in the administration of this very powerful medicine.—See the *London Medical Communications for October* 1790, vol. ii. p. 301—359.

54. *Pure barytes.*—Page 360, line 23.

Those who are desirous of forming a judgement of the comparative value of the various methods which have been adopted for the preparation of this earth in a state of purity may consult Dr. Hope in the *Edinburgh Philosophical Transactions*, vol. iv. page 36; Vauquelin in the *Annales de Chimie*, tome xxi.; Dartigues in the same work, tome xl.; and Fourcroy's *System of Chemical Knowledge*, vol. iii. page 145. For a comparative view of the respective qualities of barytes and strontian, see an

elaborate memoir by Pelletier in *Annales de Chimie*, tome xxi. page 113; or in Nicholson's 4to *Journal of Philosophy*, &c. vol. i. page 518, already referred to.

55. *Rock-salt.*—Page 362, line 27.

The impolicy of subjecting salt to a duty is now generally acknowledged; it is therefore ardently to be wished that some means could be devised of persuading our Government to abandon this tax entirely. The abundance of salt which we possess in this kingdom, has not long been of much service to the country; for in the 16th century we had no people among us who understood the art of boiling and refining salt. In 1563, an act of parliament states that "certain strangers of excellent ingine" had brought a new and improved method of making salt into Scotland, and that during fifty years these persons might make salt exclusively for the fisheries, &c.—*Statute 71 Parl. 9 Queen Marie.* Even ten years after these strangers were incorporated in Scotland for the refining of salt, the commodity was so scarce and dear, that an act passed to prohibit its exportation for three years.—*Stat. 56 Parl. 4th James VI.* The Government of France appears to be as impolitic with regard to salt as the English; for not many years ago "Buonaparté abolished the collection of turnpike dues; and a tax on salt, payable at the salt-pans, was imposed in its stead. The well-known *gabelle* was a tax on retail; and though the present impost is not so offensive in appearance, it is equally burdensome in reality." It appears that this salt-tax was imposed for the purpose of repairing the roads, at the time that the grand entrance into Italy was constructed over Mount Simplon.—See "*A Letter on the Genius of the French Government*," 8vo, Philadelphia printed, London reprinted 1810. In the year 1789, Berthollet made an excellent proposal to the French minister, viz. to remit the duty on salt for all purposes of manufacture, on condition that one pound of sulphate of iron should be mixed with every quintal of salt, which, as he says, would change its colour and alter its taste so as to prevent its being used fraudulently.—See *Annales de Chimie*, tome ii. page 182. For an account of the first discovery of the salt pits in Cheshire, of the thickness of the bed of salt, and other curious matter relating to this subject, see Dr. Holland's *View of the Agriculture of Cheshire*, 8vo, 1808, page 24 &c.

NOTES TO ESSAY VI.

ON CARBON.

56. *The diamond.*—Page 367, line 3.

In the year 1745, Mr. John Ellicott, F.R.S. ascertained the specific gravity of 14 large diamonds, with a pair of assay scales, which very sensibly turned with the 200dth part of a grain, and the mean of his experiments gave a specific gravity of 3.517.—See the *Philosophical Transactions*, No. 476. For an explanation of the principle on which the diamond carat weight was originally constructed, see Dr. Davies's *Tables of specific Gravities*, 4to, London 1750, page 19.

The largest known diamond is that mentioned by Tavernier in the possession of the Great Mogul. Its size is about that of half a hen's egg, it is cut in the rose form, and when rough, weighed 900 carats. It was found in Golconda, about the year 1550. The Pitt diamond belonging to the crown jewels of France is the most perfect and beautiful diamond yet found; it weighs 136 carats, and was purchased for 100,000*l.*, and is now valued at double that sum.

The ancients were unacquainted with the art of cutting the diamond. The four large diamonds that ornamented the clasp of Charlemagne's mantle, and which is still preserved in Paris, are uncut octohedral crystals.

The primitive form of the diamond is the regular octohedron, each triangular facet of which is sometimes replaced by six secondary triangles, bounded by curved lines, so that the crystal becomes spheroidal, and presents 48 facets. Diamonds with 12 and 24 facets are not uncommon.—Brande, vol. i. page 415. The transparent snow-white diamond is considered to be the most valuable; the green and yellow varieties are also much esteemed, and the least valuable are the gray and brownish varieties. Black diamonds are the most rare, and consequently are much prized by collectors.—Jameson's *Mineralogy*, vol. i. pages 1—14.

57. *Gunpowder.*—Page 393, line 11.

Almost every European nation makes use of a different proportion of salt-petre, sulphur and charcoal in the formation of its gunpowder, and each country pertinaciously adheres to its own proportion as the best. Bishop Watson mentions 75 parts of salt-petre, 15 sulphur, and 10 charcoal, as being the English proportion of ingredients; but from an intercourse which I have had with an eminent manufacturer of gunpowder, since the Essay on Carbon was printed, I have learnt that very little of

the gunpowder made in this kingdom, except what is required for the service of the Government, or the best description of gunpowder for the use of gentlemen for killing game, contains so much salt-petre as is stated by the bishop. A particular detail of the methods formerly adopted in making gunpowder is printed in Sprat's *History of the Royal Society*, 4to, London 1667, page 277.

Before the introduction of gunpowder, an highly inflammable compound called the *Greek fire* was in use; and this, having the property of burning under water, could not easily be extinguished; consequently it did surprising execution. In the 12th century the Emperors of Constantinople used to send quantities of this dreadful combustible to princes in friendship with them, as the most valuable present they could give them, and the greatest mark of their favour. This was considered to be so important an article of offence, that the use of it was continued long after the introduction of gunpowder; for it appears, when an English army commanded by the Bishop of Norwich besieged Ypres in the year 1383, the garrison defended themselves so well with stones, arrows, *Greek fire*, and certain engines called *guns*, that they obliged the English to raise the siege with such precipitation, as to leave their great cannon, which were of inestimable value, behind them.—Walsingham (Thomæ) *Historia Brevis ab Edwardo I. ad Henricum V.* folio, London 1574, page 303. It is difficult to discover the exact time of the introduction of gunpowder; but if we may credit John Barbour, the monkish poet, Edward the Third employed cannon in his first campaign against the Scots in the year 1327. Barbour's *Metrical Life of King Robert Bruce*, page 408. Edward the Third unquestionably had cannon in his army at the siege of Calais in the year 1346, though the balls then made use of, and for many years afterwards, were probably formed of stone; for in the year 1419, King Henry the Fifth gave a commission to John Louth, clerk of the ordnance, and John Bennett, stone-mason of Maidstone in Kent, to impress a sufficient number of men to make 7000 cannon balls in the quarries of Maidstone-heath.—Rymer's *Fœdera*, vol. ix. page 542. Not but that balls of iron had been used *before* this period; for at the siege of Cherbourg, in the year 1418, the inhabitants "discharged red-hot balls of iron into the English camp to burn," as they state, "the huts in which the soldiers were lodged."—Elmham's *Life of Henry V.* page 155.

Iron cannon, however, were not made in England for a long time after they had been in use on the continent, as the first foundry of this kind is said to have been formed in 1535 by an individual of the name of Owen; and in the year 1547 one Pierre Baudet, a foreigner, cast iron cannon in the neighbour-

hood of London. The first reference in Rymer to the use of iron cannon balls is in 1530.—Rymer's *Fœdera*, vol. xv. p. 18.

58. *Nitre.*—Page 294, line 6.

"The history of the making of salt-petre by Mr. Henshaw," together with directions how to proceed in refining it, was published in Sprat's *History of the Royal Society*, 4to, p. 260—276. An elaborate memoir by Chaptal, on the formation of salt-petre and the establishment of artificial nitre beds, will be found in the *Annales de Chimie*, tome xx. page 308—369. An account of the French method of procuring salt-petre since the Revolution, may be seen in the *Tradesman's Magazine*, vol. ii. p. 533. From the experience which I have had in the preparation of salt-petre for the manufacture of nitric acid, I am inclined to think, that the process of refining nitre by repeated solutions in water, is not thoroughly understood in this country. The following table constructed by Hassenfratz and printed in the *Annales de Chimie*, tome xvii. page 135, is calculated to be of great use to those who are engaged in this employment. On the origin and formation of nitre, consult the Earl of Dundonald's *Treatise on the Connection between Agriculture and Chemistry*, 4to, London 1803, page 59.

Hassenfratz's Table of the Quantity of Nitre in various aqueous Solutions of this Salt.

Pounds of Nitre in 100 pounds of the Solution.	Specific Gravity of the Solution at 61° Fahrenheit.	Pounds of Nitre in 100 pounds of the Solution.	Specific Gravity of the Solution at 61° Fahrenheit.
1	1.006	14	1.085
2	1.012	15	1.091
3	1.018	16	1.098
4	1.024	17	1.105
5	1.030	18	1.111
6	1.035	19	1.118
7	1.040	20	1.125
8	1.046	21	1.132
9	1.053	22	1.138
10	1.059	23	1.145
11	1.065	24	1.152
12	1.072	25	1.158
13	1.078		

In the xixth volume of the *Annales de Chimie*, page 365, it is announced that M. Lowitz has published in Crell's *Chemical Annals for the year* 1792, a new Essay on the purification of

salt-petre by powdered charcoal. On the means of refining nitre, the reader may consult the *Repertory of Arts and Manufactures*, vol. v. p. 129, and the same work, vol. viii. p. 199.

59. *Deposits tar.*—Page 398, line 31.

The tar procured from any wood that does not produce turpentine, will not mix with the tar commonly imported for naval purposes from America and the Baltic, especially as, in the unimproved state in which this tar is first produced, it retains a portion of pyroligneous acid, and hence it is to a certain extent miscible with or affected by water; but Messrs. Harper and Wilson have discovered a method, secured to them by a patent right, of purifying this tar so as to make it resist water equally well with foreign tar, and from the tar so purified pitch may be obtained superior to any Baltic or American pitch. Some years ago the inside of the sheets of copper composing the sheathing of several ships was coated with a lacker prepared from such pitch, under the direction of Messrs. Harper and Wilson; but I have not yet heard the result of these experiments. It is, however, to be hoped that the patentees will at some future time feel the benefits which ought to result to them from the discovery of purifying a residuary article which is now produced in this country in considerable quantities.

60. *Ink of the ancients.*—Page 412, line 9.

A writer of the 16th century recommends "the preparation of an aqueous decoction of galls, and that when ink groweth thick to thin it with this rather than with beer, vinegar, or any other fluid."—Platt's *Jewel House of Nature and Art*, page 43. There is great room for improvement both in the manufacture of writing- and printing-ink. Dr. Lewis has written on both these kinds of ink with great knowledge of his subject.—See the *Commercium Philosophico-Technicum*, pages 371—401. It seems extraordinary, but for a long time much finer ink for the use of the printer was manufactured at Madrid than in any other part of Europe. "The art of printing was carried into Spain by the Germans, who travelled from city to city with their types and presses. *Ibarra*, who is well known by his superb edition of Don Quixote in four volumes, 4to, employs an ink so superior to all others, that our printers have often endeavoured to discover the secret of its composition, the works which he published having rivalled those of the renowned Bodoni of Florence. Punches, matrices, types, and paper, are all frabricated in Spain, not only at Madrid, but also in several of the provinces; where the Spanish presses have produced editions of books not less fine than that of the Sallust printed by Don Gabriel the younger."—See *The Campaigns of the French*

Armies in Spain and Portugal in the Years 1808 *and* 1809, *with a statistical Description of those Kingdoms*, 8vo, Paris 1809. Excellent directions by Desormeaux for making good writing-ink may be seen in the *Philosophical Magazine*, vol. v. p. 158. Some important remarks by Ribaucourt on the same subject will be found in the *Repertory of Arts*, vol. ix. page 205.

61. *Heated by steam.*—Page 416, line 12.

The principle of heating liquids by steam has been applied in France to the purposes of distillation. A person of the name of Edward Adam appears to have been the first successful practitioner of this principle, for the purpose before mentioned. His processes and apparatus are described in a work entitled "*Recherches sur l'Etat actuel de la Distillation du Vin en France, et sur le Moyen d'améliorer la Distillation des Eaux de Vie de tous les Pays*," Paris 1811, par M. A. S. Duportal. By this work it appears that spirits may be distilled from malt-wort, worts from saccharine roots and substances, or from fruits, without any burnt taste;—a circumstance of the utmost importance to distillers as well as to the nation. In a financial view this may also be very important, as it is likely to render ardent spirits made at home so much cheaper and better as to prevent in some measure the inducements to smuggling. "On the use of steam as a vehicle of heat," see Rumford's *Philosophical Essays*, No. xv. vol. iii.

62. *Reduction of ores.*—Page 428, line 29.

The very laudable plantations of larch and other fir trees which of late years have been made, and which are continually making upon waste and poor land in every part of Great Britain, will probably, at no very distant era, not only furnish charcoal enough for the manufacture of British bar-iron, and hence preclude the necessity of sending to Sweden and Russia for an article which is allowed to be superior to what we now manufacture at home, but these woods will also yield pitch, tar, rosin, turpentine, deal boards and fir timber for our own consumption, without having occasion to resort to importation to any very considerable amount. For a list of those noblemen and gentlemen who have been the most eminent benefactors to their country in this way, the reader is referred to the several volumes of the *Transactions of the Society instituted at London for the Encouragement of Arts, Manufactures and Commerce*, from the year 1783 to the present day. Ample directions respecting the different methods to be pursued in planting timber, with various calculations of expense, and the profits resulting from the produce, will be found under the article *Plantation* in Dr. Rees's *Cyclopædia*, vol. xxvii. part ii. M. Reaumur proposed

some interesting experiments respecting timber; but they were such as could only be made by the government of a country. He wished to have cut each year the same number of acres of wood, and to have the produce exactly weighed, that the annual increase might be compared during a long succession of years, in order to discover the age when the increase of the respective species of wood begins to diminish. Experiments are also wanting to determine what trees can grow together without injuring each other. The oak and the fir are said reciprocally to damage each other.

63. *Native materials.*—Page 457, line 21.

I have met with a passage which so exactly coincides with what I have said respecting the policy of exporting none of the native materials which we can ourselves fabricate, that I cannot resist the pleasure of transcribing it. "EITHER EXPORT OR CONSUME," says M. Seigneaux de Correvon to the Economical Society of Berne in Switzerland. "The truth of this maxim," continues he, "cannot be contested, the alternative is indispensable. There must either be a liberty without shackles, or an interior consumption by a number of inhabitants proportioned to the means of nourishing them. Thus, under the reign of Queen Elizabeth, in England, the exportation of wool was prevented: from thence the manufactures and arts increased the number of men, and the exportation of corn also permitted the same augmentation, by the immense profits which were opened to cultivation. It is therefore clear, that all raw materials which may be further wrought should be kept at home, until they have acquired, by the labour of the inhabitants, all the value of which they are susceptible."—*Prize Essays on the Spirit of Legislation*, 8vo, London 1772, page 406. It is reckoned that a million in unwrought materials produces from six to ten millions when fabricated.—*Ibid.* page 59.

64. *Woollen manufacture.*—Page 458, line 5.

Although the woollen manufacture appears to have been lost in the reign of Henry III., Edward I., and throughout the dark ages, there is abundant testimony that the ancient Britons were very famous for the manufacture of woollen cloth. Pliny says that "the ancient Britons made a kind of cloth or felt which was so strong and firm, when vinegar was used in making it, that it resisted the blow of a sword, and was even some defence against fire. In after times, these arts were much improved amongst us by the Romans, who formed colleges and corporations, with various privileges, for instructing the people, and improving the manufacture of all articles made of woollen. One of these imperial manufactories, according to Camden, was

established on the spot where the city of Winchester now stands. These efforts were so successful, that some hundred years afterwards we find that the fleece, by the Anglo-Saxon laws, was valued at two-fifths of the price of the whole sheep. In after times, King Edward III., as I have already stated in the text, took so much pains to improve this important manufactory, that during his reign it became completely established. This appears evident from a curious paper published by Mr. Rymer, containing a grant from Richard II. in the year 1382 to Cosmo Gentilis, to export several pieces of cloth of various colours, without paying any duty; the first article of which consists of six pieces of tapestry of a green ground powdered with roses, which the King sent as a present to the Pope.—Pliny's *Natural History*, book viii. chap. 48. *Cod. Theod.* tome iii. page 524. Camden's *Britannia*, vol. i. page 139. Wilkins's *Leges Anglo-Saxonicæ, &c.* page 23. Rymer's *Fœdera*, vol. vii. page 356. Henry's *Hist. Great Britain*, 8vo, vol. viii. page 285.

NOTES TO ESSAY VII.

ON SULPHURIC ACID.

65. *From sulphate of iron.*—Page 467, line 15.

I have stated that the sulphuric acid formerly made in this country was procured from sulphate of iron; but I forgot to notice that the oil of vitriol which is prepared in this way, gives out acid fumes when it is exposed to a damp atmosphere. It also congeals sometimes and crystallizes as it were, and hence such acid acquired the name of *glacial* oil of vitriol. From these circumstances it is evident that it must differ in a considerable degree from the sulphuric acid as it is now usually prepared. Dr. Thomson considers it to be of greater strength than the common sulphuric acid, that it is pure anhydrous acid; but Professor Brande thinks it more probable that it consists of sulphuric acid, combined with a portion of sulphurous acid. The subject deserves further examination, especially as so much sulphuric acid is now made by a patent process from martial pyrites or sulphuret of iron.

66. *Martial pyrites.*—Page 468, line 5.

In the year 1818 Thomas Hills and Uriah Haddock, of Bromley in the county of Middlesex, obtained a patent for making sulphuric acid from martial pyrites, or other native sulphurets, without the use of nitre. The process consists in submitting these native productions to a red heat in a reverberatory fur-

nace, and conducting the fumes arising from the combustion into a leaden chamber formed as usual, and with the floor covered with water. As these patentees have made offers to various other manufacturers to sell them the right to make use of this process, they have stated that the sulphur passes in the act of combustion at once into the state of sulphuric acid, without the aid of nitre.

Having expressly written on the manufacture of sulphuric acid, I have thought it right to apprize my readers of the existence of this patent, and to give it as my decided opinion, that what they profess to do is utterly impossible. I know Messrs. Hills have a large establishment for the production of sulphuric acid from iron pyrites, and I have reason to think that the sulphuric acid they make is of very good quality; but I believe it is not made without a considerable quantity of nitre, though they have thought fit entirely to omit the mention of that article in their specification. They speak of throwing steam and some *imponderable* substance into the leaden chamber occasionally; but what this imponderable substance can be, it is impossible to imagine, as it is well known that nothing except nitre has yet been discovered, that can with economy be employed to convert sulphurous to sulphuric acid.

67. *Acid, sp. gr. of* 1.8494.—Page 500, line 18.

Since I published the Table on the specific gravities of sulphuric acid, when diluted with different portions of water, it has been suggested to me by some makers of oil of vitriol in the north of England, that the manufacturers in that part of the kingdom agree universally in selling the acid, when concentrated, of the specific gravity of 1.8436, or 29½ ounces avoirdupois to the wine-pint, and therefore the table would have been more useful to them, if I had taken oil of vitriol of this specific gravity for the standard acid, instead of the acid of 1.8494 which I employed. I mention this circumstance merely to have the opportunity of assuring my readers, that if I find this objection become general, I will endeavour to construct a new table on that principle, and shall print the same either in one of the periodical journals, or in a new edition of these Essays, should a new one be required by the public.

NOTES TO ESSAY VIII.

ON CITRIC ACID.

68. *Wood of the citron.*—Page 540, line 6.

The CITRON-TABLES so often spoken of by Pliny and others, and so highly prized by the ancient Romans, could have had no connexion with the fruit of that name; for the wood of which they were made appears to have been a distinct class of timber found in Africa, and in modern times brought from America. In support of this idea I quote Robert Ainsworth, who explains the word *citrus* thus: "A citron tree," says he, "growing in Africa, upon the hill Atlas, of the wood whereof they made tables at Rome; also another sort, which bore fruits of an excellent grateful smell." Horace speaks of erecting marble monuments under *citron* temples, near Albania: ode i. book iv. The value which the emperors and opulent citizens of Rome set upon their citron tables, surpassed that of any other furniture in ancient or modern times. Pliny among other particulars relates, "There is this day to be seen a board of citron wood, belonging some time to M. Tullius Cicero, which cost him 10,000 sesterces. Much speech there is besides of Gallus Asinius his table, sold for 11,000 sesterces. Moreover there are two others which King Juba sold, the one was at 15,000 sesterces and the other held little under. A mountain in high Mauritania called *Anchoranius* did yield the best and fairest trees, but it is now despoiled of them. The barbarians, to season the wood, bury the green boards within the ground, and smear them over with wax; but the workman puts them in heaps of corn for seven days, and stays seven days more before they be wrought, and it is wonderful how much the wood loses in weight by this means. Nor do the tables take harm or stain, if wine be spilled upon them." The Roman sestertius was equal to 1*d.* 3¼*qrs.* sterling, consequently Juba's table was valued at more than one hundred and twenty pounds of our money. —See Holland's *Pliny*, vol. i. book xiii. chap. xv. page 395. At this day we import timber from America called *citron wood*, and by the natives candle-wood, because small pieces of it burn like a candle: the same species of tree grows also in abundance in the Leeward Islands. It may not be entirely impertinent to remark, that in modern times we have beautiful cabinet articles made with rose-wood; but it is well known that this has no connexion whatever with the shrub of that name, it being the product of a large timber tree, a native of the island of Rhodes, and growing also in some parts of the East Indies. In like manner we may suppose that the Romans gave the appellation of citron-wood to one of their most favourite and rare speci-

mens of timber, a description which could not agree with the lemon-tree, for this had for ages been abundant in the Italian states. Pliny remarks that "Theophrastus says not a word of these citron tables, and therefore he believes none such were made before the time of Cicero."—*Ibid.* page 396.

69. *Spoil in keeping.*—Page 540, line 16.

I was surprised to see a paper expressly on the best methods of preserving lemon juice in Platt's book, which was printed in the latter end of the 16th century. He says that "if it be merely passed through a fine filter and then put back again into the cask, this will be very effectual towards preserving it.—Platt's *Jewel House of Art and Nature*, part iii. page 36.

70. *Separating the mucilage.*—Page 541, line 14.

The mucilage contained in lemon or lime juice has always been considered to be the main obstacle to the crystallization of the citric acid contained in the expressed juice of these fruits. Having lately, however, seen a Report made to His Majesty's Victualling Board by an eminent chemist, stating that the concrete acid may be obtained from lemon juice by the simple mode of evaporation only,—an assertion contradicting every thing which I had hitherto observed respecting the concentration of this article,—I wrote to a friend who has had more experience than myself in the preparation of concrete citric acid, and received the following reply to my letter: "An attempt to procure the crystallized acid by the mere evaporation of the lemon juice was," says he, "among the earliest experiments I made on this subject. The simple evaporation of the juice, I find, produces merely a thick treacley kind of substance, and by pushing the concentration further, it may be brought into the state of honey. I still prosecuted the inquiry, in the vain hope of being able to procure a concrete acid by the agency of lime. The mass procured by evaporation I diluted with cold water, making my solution about four or five times the strength of good lemon juice. To one pint of this solution I added one ounce of alcohol; and having reduced this one-fourth by evaporation, it was set aside to cool. On the following day I found a considerable precipitate, which I separated by filtration, and I again evaporated the mother liquor. This treatment I continued from time to time till the whole was reduced to a thick substance similar to molasses as before, but there was no sign of any tendency to crystallization. I repeated this experiment with different proportions of alcohol, but the result was always the same; and I closed the series of experiments with a conviction of the impossibility of procuring concrete citric acid by the mere evaporation of lemon juice."—For further information on the

crystallization of citric acid see the 15th volume of *The Repertory of Arts and Manufactures*; also volume xii. of the same work, page 347.

71. *State of concentration.*—Page 559, line 15.

What I have said in this place, respecting the dilution of sulphuric acid to be employed in the decomposition of the citrate of lime, was a conclusion drawn from my own experience, and I have still good reason for believing that I am correct in that recommendation; but it must not be concealed that a person who has also had much experience in this business, has lately assured me that he employs only 2 gallons of water with every 7lbs. of concentrated sulphuric acid, and has found no inconvenience whatever in the practice.

72. *Chalk from England.*—Page 570, line 28.

Great Britain has in all ages been celebrated for its abundance of chalk and lime-stone; and as there are many parts of the continent of Europe where no trace of this earth can be found, chalk, lime-stone and marle, have always constituted a portion of the British exports; and there is reason to believe that this trade was carried on by a class of men known by the name of chalk merchants, long before the establishment of Christianity in this island. In the year 1647, several tablets were dug up near Domburgh in Zealand, among which was one with the following inscription:

DEAE NEHALENNIAE
OB MERCES RECTE CONSER
VATAS SECUND. SILVANUS
NEGO † TOR CRETARIUS
BRITANNICIANUS.
V. S. L. M.

To the goddess Nehalennia
For his goods well preserved
Secundus Silvanus
A Chalk Merchant
of Britain
Willingly performed his merited vow.

73. *The cranberry.*—Page 572, line 4.

As the fruit of this shrub is much employed for domestic purposes, some persons may be glad to be informed that these berries may be preserved in a good and perfect state for several years, merely by drying them a little in the sun, and then stopping them up closely in dry bottles. An infusion of the young

twigs of the *solanum dulcamara* is, according to Linnæus, an admirable medicine in acute rheumatism.

74. *Cynosbatus vel rosa canina.*—Page 572, line 10.

The pulp of these berries beaten up with sugar makes the conserve of heps of the pharmacopœia. Mixed with wine it has long been considered a very acceptable treat in the north of Europe.

75. *Prunus cerasus.*—Page 572, line 15.

The gum which exudes from this tree is used for a variety of purposes in the arts: it is extremely nutritive, and equal in every respect to gum Arabic. Hasselquist in the account of his travels, relates that a hundred men, during a siege, were kept alive for nearly two months without any other sustenance than a little of this gum taken occasionally into the mouth and suffered gradually to dissolve. The wood of the *prunus cerasus* is in great estimation with the turner.

76. *Known to the ancients.*—Page 581, line 2.

The whole passage from which the motto to this Essay was taken runs thus:

> Media fert tristes succos, tardumque saporem
> Felicis mali:—quo non præsentius ullum,
> (Pocula si quando sævæ infecere novercæ,
> Miscueruntque herbas, et non innoxia verba,)
> Auxilium venit, ac membris agit atra venena.
> Ipsa ingens arbos, faciemque simillima lauro:
> Et, si non alium late jactaret odorem,
> Laurus erat: folia haud ullis labentia ventis:
> Flos ad prima tenax: animas et olentia Medi
> Ora fovent illo, et senibus medicantur anhelis.
>
> VIRG. Geo. ii. 126—135.

The translation made use of for the motto was Sotheby's, that by Warton is as follows:

> The Median fields rich citron fruits produce,
> Though harsh the taste, and clammy be the juice;
> Blest antidote! which, when in evil hour
> The stepdame mixes herbs of poisonous power,
> And crowns the bowl with many a muttered spell,
> Will from the veins the direful draught expell.
> Large is the trunk, and laurel-like its frame,
> And 'twere a laurel were its scent the same;
> Its lasting leaf each roaring blast defies,
> Tenacious of the stem, its flowrets rise:
> Hence a more wholesome breath the Medes receive,
> And of their Sires the lab'ring lungs relieve.
>
> WARTON's Translation of VIRGIL's *Georgics*.

77. The nature of this singular acid.—Page 596, line 20.

That nothing of importance may be omitted which respects this acid, the following circumstances, for which I am indebted to Dr. Thomson, may be added to the numerous facts already detailed in the preceding Essay:—

Chlorine converts gum into citric acid, according to the experiments of Vauquelin. This chemist passed a current of chlorine gas through a diluted solution of gum in water. In a few days almost the whole of the gum was acidified; and he detected citric acid by the formation of super-citrate of lime, soluble in water, and decomposable by oxalic acid. If nitric acid be slightly heated upon gum until it has dissolved it, and until a little nitrous gas is exhaled, the solution on cooling deposits *saclactic* acid. *Malic* acid is formed at the same time; and if the heat be continued, the gum is at last changed into *oxalic* acid. Thus, no less than four acids are formed by the action of nitric acid on gum. We are, however, indebted to Mr. Cruikshanks for the most precise experiments on the quantity of oxalic acid obtainable from gum by nitric acid. By digesting 480 grains of gum with 6 ounces of nitric acid, he obtained 210 grains of oxalic acid. No artificial tannin is formed during this process.

END OF THE FIRST VOLUME.

PRINTED BY RICHARD TAYLOR, SHOE-LANE, LONDON.